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Effect of Land-Use Management Systems on Coupled Hydraulic Mechanical Soil Processes Defining the Climate-Food-Energy-Water Nexus Rainer Horn



*Institute for Plant Nutrition and Soil Science,
Hermann Rodewaldstr. 2, 24118 Kiel, Germany.*

Corresponding Author: Rainer Horn, e-mail: rhorn@soils.uni-kiel.de

Abstract

Soils are the most critical life-supporting compartments of the biosphere. They provide numerous ecosystem services such as habitat for biodiversity, water and nutrients, as well as producing food, feed, fiber and energy. Soils undergo intense and irreversible changes due to a non-site adjusted land management and improper application of machinery and techniques in its broadest sense. In combination with the growing population (until 2050 we will have approx. 9 Billion people) the urgent need for a more reliable dataset of soil properties and soil functions gains in importance in order to even prepare more reliable models for various requests. The mechanical strength – the precompression stress - as the result of geo-, pedo- and anthropogenic long-term processes - can be defined as the basis for quantifying the rigidity boundary. It distinguishes between the recompression stress (i.e. elastic, rigid properties) and the virgin compression stress range where plastic deformation including irreversible changes of properties and functions occur. The changes in the hydraulic or pneumatic functions like hydraulic or air conductivity, the pore size distribution primarily all occur in the virgin compression stress range, The same is also true for redox reactions and the biological activity (respiration) in soils but also carbon sequestration potential is also linked with the precompression stress value. Thus, a more precise definition and following of site-specific functionality differences, which may exclude or concentrate certain land use or management forms are needed, in order to optimize yield, soil protection and a sustainable land use management considering the limited site specific resilience at the same moment.

Key words: stress/strain, stress distribution, precompression stress, coupled hydraulic and mechanical processes, ecological functions

Introduction

The properties of arable or forestry soils, or the substrate for horticulture, or landscape planning, are the basis for not only food production, filter and buffer for clean drinking water and sufficient groundwater recharge but they are also the basis for raw material, biological diversity as well as soils are archaeological documents. However, soils as three phase systems have only a limited resilience and exceeding these boundary conditions result in soil degradation, which is mostly irreversible. Very often, either soil classification is based on properties, which were defined from completely homogenized material, or capacity parameters are defined for both homogenized and aggregated soil samples. Well-known parameters are cation exchange capacity, air capacity, or plant available water. However, such data may not define or predict soil processes adequately because neither the accessibility of

particle or pore wall surfaces nor the connectivity between pores within structured soils are considered. In the following, these interactions are discussed in order to define soil functions like redox reactions cation exchange intensity, or air permeability, hydraulic conductivity and actual soil strength. Furthermore, the coupling of physical, chemical and biological processes is mandatory in order to obtain a more complete picture of in situ conditions as the basis for the quantification of the boundary conditions for a sustainable land use management.

Stress strain and alterations of soil structure

According to the European Soil Framework Directive (2006) soil compaction is besides water and wind erosion one of the main physical reasons and threats of soil degradation. It is estimated, that 32% of the subsoils in Europe are highly degraded and 18% moderately vulnerable to compaction. The problem is not limited to cropland or forest areas (especially because of non-site adjusted harvesting machines) but it is also prevalent in rangelands and grassland, and even in natural non-disturbed systems. Wheeling during seedbed preparation or harvesting as well as animal trampling are main factors leading to soil degradation and biodiversity changes or losses. A decline of soil physical quality and changes in soil properties such as internal soil strength, precompression stress, infiltration rate, continuity of soil pores, air and hydraulic conductivity are considered as expressions of soil degradation (Horn, 1985, Krümmelbein 2007, Lei Gan 2012, Keller et al 2007, Keller et al. 2013, Berisso et al, 2012, Hartge and Horn 2016). In this context also the frequency of wheeling or trampling in combination with the actual matric potential and internal soil strength are examples of coupled processes and the outcome can either enhance the deterioration of existing soil structure by the formation of even stronger platy structure with more negative ecological properties. However, it can also result in complete structure deterioration due to shearing, puddling, and consecutive homogenization. Both processes can be classified as long-term irreversible and result not only in an increased sensitivity of such sites for consecutive water or wind erosion but also in an irreversible loss of soil properties or functions as well as crop yield or plant growth.

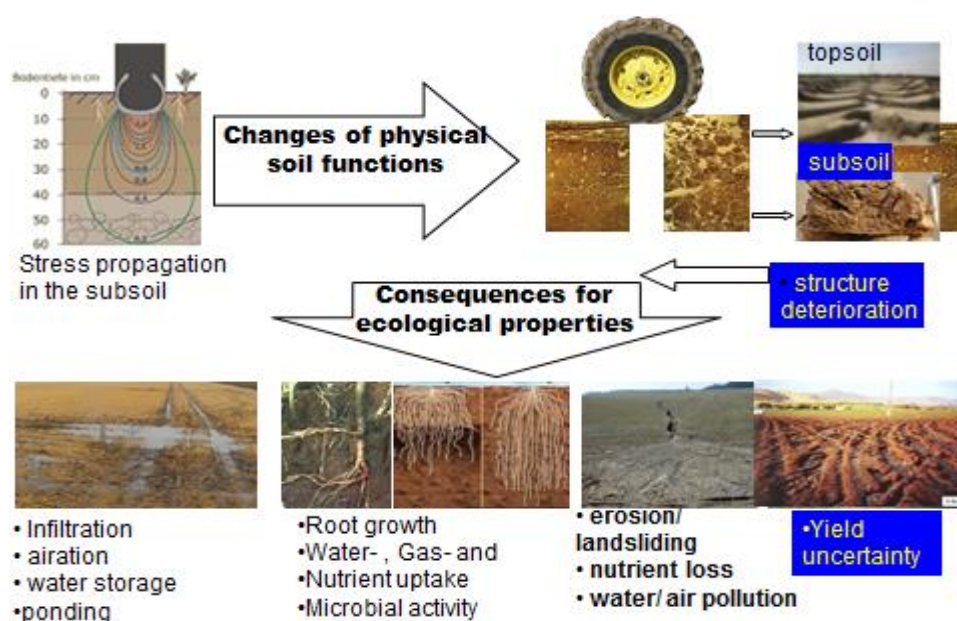


Figure. 1. Soil degradation threats

Figure 1 informs about some main soil degradation threats. Negative effects of soil mismanagement resulting in soil compaction, soil erosion including reduced filter and buffer processes and crop yield are well documented. However, the relation of sustainable soil properties to a well-defined parameter like soil rigidity as a link to interactions with chemical, physical and biological soil properties are still not completely understood as it seems to lack on a wider range of data.

Some information on mechanical properties and related dynamics

Soil compressibility defines the sensitivity of the pore system to mechanical stress application i.e. the susceptibility to soil compaction. One of the main parameters, commonly used to quantify soil strength is the precompression stress. It quantifies the stresses to which the soil was exposed in the past, irrespective of its origin. Pedogenic, anthropogenic or even geogenic processes or various hydraulic conditions and land management can cause altered soil strength even if its origin remains mostly unknown under in situ conditions – the direct link to any of these parameters fails under unknown in situ conditions (Fig.2). The precompression stress value can however be applied to quantify the overall strength range which is equivalent to the soil rigidity.

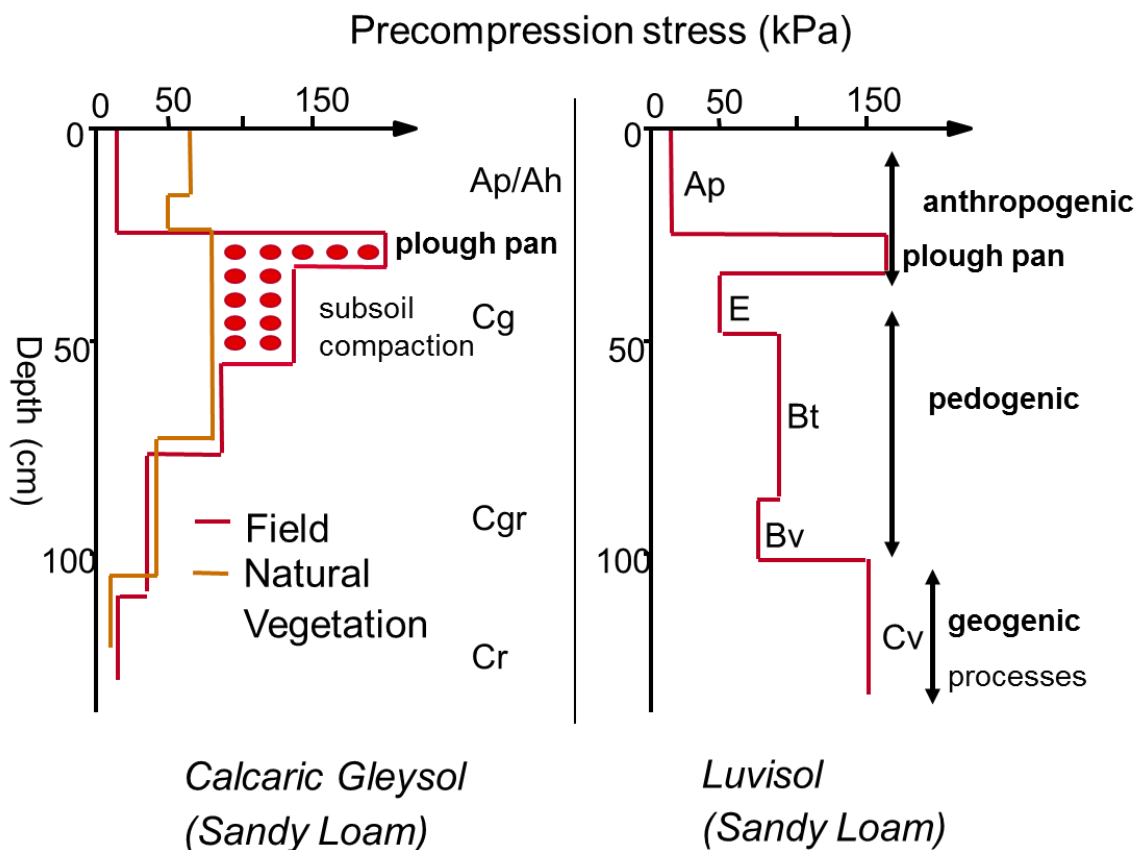


Figure 2. Soil strength defined as precompression stress for a Calcaric Gleysol and a Luvisol.

This direct relation between soil strength defined as precompression stress and soil rigidity also includes the dominant elastic behavior which results in permanent structure dependent soil functions (with a reversible deformation) if the actually applied stresses do not exceed the precompression stress value. Stresses higher than the precompression stress value

result in a further plastic (irreversible) deformation (Horn 1981, Horn et al., 1995, Horn and Peth, 2011). This statement holds always true, if stresses are applied statically, while mostly dynamic stress application may cause a more intense soil deformation due to the rearrangement of particles, which then result in a new “dynamic equilibrium” under those conditions. In combination with altered hydraulic stresses it may even result in a complete puddling and weakening of soil structure (Krümmelbein et al. 2006, Bi et al., 2015).

The principles of aggregate formation and degradation based on swell /shrink but also its alteration due to mechanical stress application and the combination with hydraulic stresses are summed up in Fig. 3.

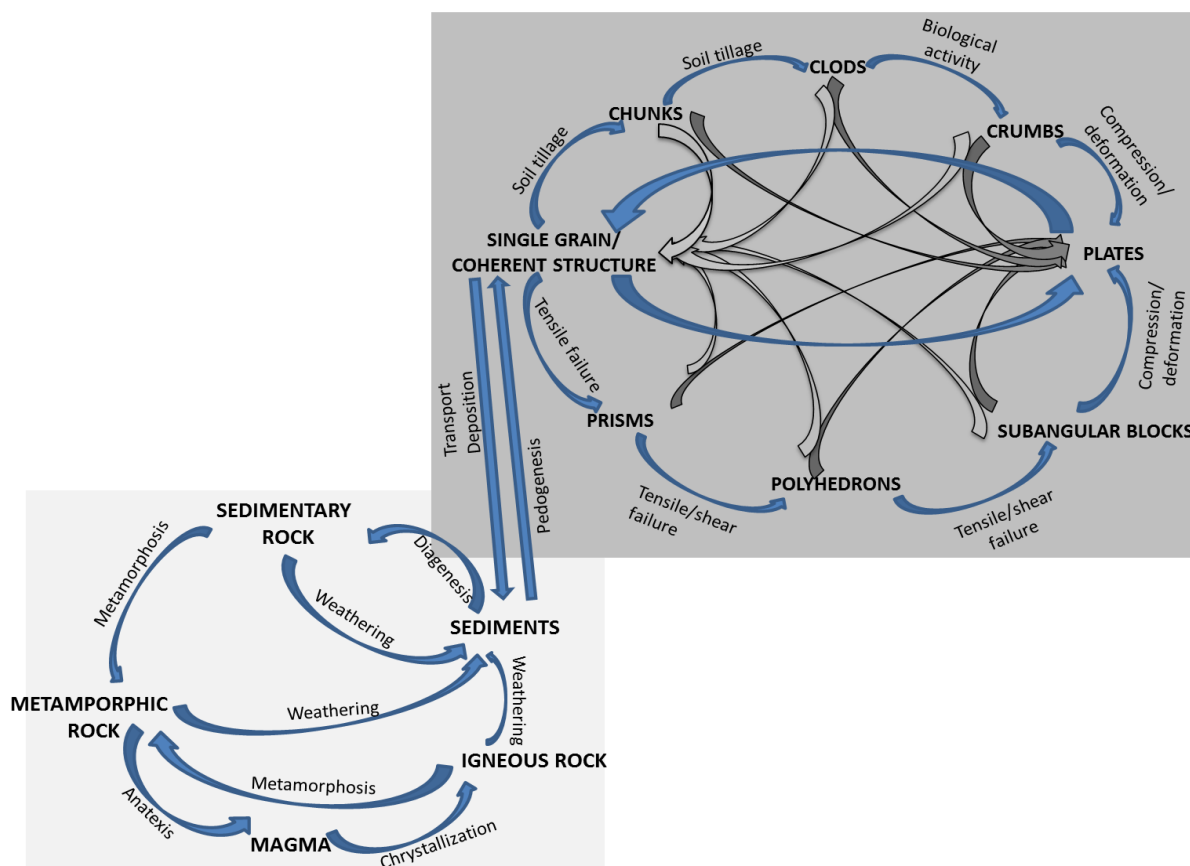


Figure 3. *Soil Structure Formation and Degradation (after Krümmelbein and Horn 2011)*

The initiation of aggregate formation due to shrinkage and swelling always causes tensile cracks and the formation of prismatic structure while after repeated wetting and drying a new dynamic equilibrium will be reached due to more pronounced shear failure processes (Fig.3). The typical aggregates: blocky or subangular blocky structures are defined by non-rectangular shapes and increased soil strength. Accumulation of organic matter and its decomposed constituents furthermore strengthen these aggregates. Crumbs as typical biologically formed aggregates are strong and often defined as macroscopic homogeneous. All aggregate types have however a limited internal strength as can be seen from the pattern of the Mohr Coulomb failure line (Fig.4) With more pronounced structure formation increase the cohesion and angle of internal friction values. However, as soon as mechanical stresses exceed these limits, will coarse pores in between aggregates be destroyed followed by intraaggregate pores. A shear induced rearrangement of particles and the partial height change rectangular to the stress

application finally forms a platy structure with an increased intraaggregate cohesion, but a reduced friction between the single particles (as a consequence of the rearrangement). Consequently, platy structure is defined by the highest cohesion but very small values for the angle of internal friction.

It must be furthermore stated that irrespective of whether the mechanical loading results from wheeling or from animal trampling, it can have an enormous effect on strain and consecutive homogenization processes if the hydraulic boundary conditions are still not equilibrated with the stress and kind of loading. If during the short term stress application the actual structure status coincides with pore deterioration and the pore water pressure cannot be equilibrated within short time even a complete weakening like during puddling or kneading occurs and may result in a complete homogenization of the former structural system (Krümmelbein et al., 2009). Aggregate formation also affects the internal flux processes and directions and alters the filter and buffer functions due to varying accessibility of pore surfaces or connectivity (Fig. 4). In this context we have to differentiate between the ecological effects of the whole soil profile with limited pore continuity and accessibility and the dominant flow directions with limited access to all surfaces or pores. Horizontal crack formations e.g. in plow pan layers, under ruts or in glacial till parent material creates dominant horizontal fluxes defined as horizontally anisotropic with restricted access of deeper soil layers for infiltrating water and a consistent increase in lateral soil erosion by water.

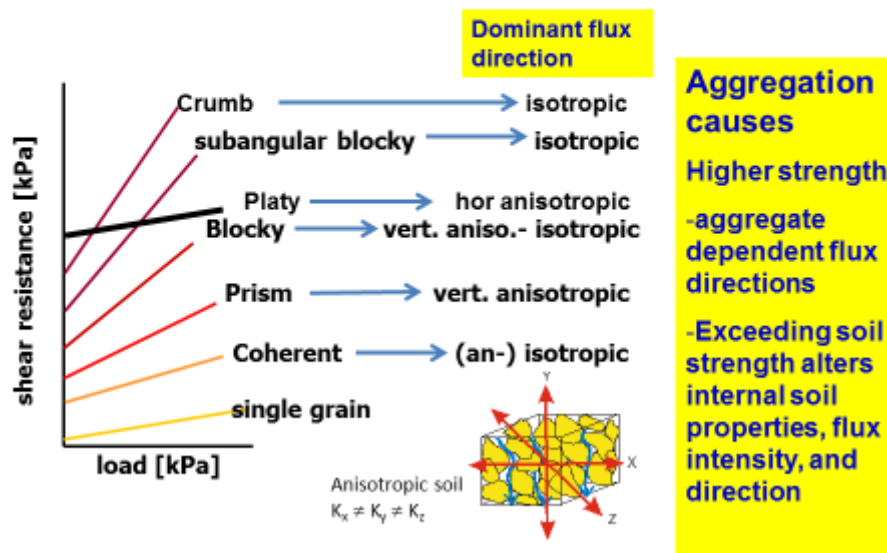


Figure 4. Aggregate dependent pattern of the Mohr Coulomb failure lines and associated dominant flux directions.

It is obvious, that structure dependent formation of interaggregate pore systems always affects pore continuity and directions and alters the values of the corresponding three-dimensional flux tensors or water, gas, heat, and ions.

Effect of stress application on changes in ecological soil functions

Capacity or intensity parameters

In soil sciences literature (e.g. Scheffer Schachtschabel, 2016, Huang et al., 2012, Brady and Weil, 2008) are primarily capacity parameters like cation exchange capacity, air capacity or plant available water (capacity) related to e.g. plant growth, yield or to environmental processes. This approach is certainly less straightforward than intensity parameters, which themselves are only valid in the rigidity ranges (Horn and Kutilek, 2009). However, such approach and the link to mechanical or hydraulic stresses amongst others improve the reliability of predictions for all kinds of hydraulic, mechanical, chemical or even climatic soil interaction processes.

Changes in soil functions like hydraulic conductivity, air permeability, redox potential, cation exchange intensity must be therefore related to parameters like precompression stress, aggregate strength, cohesion and angle of internal friction. These strength parameters are appropriate to document the transition from elastic to plastic (= irreversible) changes in soil functions.

A quick approach to quantify stress induced changes of soil properties and consequences for ecological processes is the description of the rooting pattern, as it shows the effects of structure formation on plant growth, altered or even prevented accessibility of nutrients, water, air and the anchorage of the plant (Fig. 5).

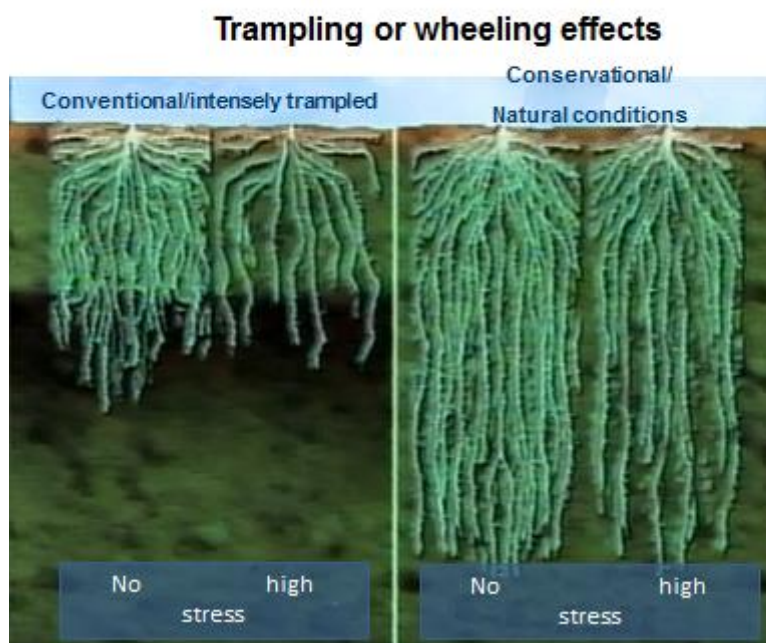


Figure 5. Root growth and depth in soils: effects on availability and accessibility

It is obvious, that deep rooting in soils is mostly prevented through a platy structure e.g. under conventional tillage or intensely trampled conditions and can be even furthermore reduced if more stress is applied. Conservation tillage or natural conditions with stronger aggregates and less dense conditions at the same time result in an even and deeper rooting,

which guarantees a better plant growth with increased accessible particle or pore surfaces. The actual topic of carbon sequestration in soils to combat climate change effects is also linked with the accessibility and availability of particle or pore surfaces. However, it must be stated, that exceeding the internal soil strength i.e. the precompression stress results in a reduced rooting depth and intensity and less positive effects.

Furthermore, intensity parameters are mostly vectors and sensitive markers for soil properties changes in directions and time. Thus, pedogenic, geogenic or anthropogenic processes and their effects on flux processes or interrelated changes in biological, physical, and chemical functions including filtering and buffering, soil water erosion, or even the gas emission are direction dependent. They differ in quantity and quality at the given structure conditions and can be only quantified and extrapolated within the rigidity range of the pore system. Furthermore are the actually existing properties as the result of former management reference points for additional changes when exceeding the rigidity of pore functions.

Interaction between mechanical and hydraulic properties

Soil deformation due to applied mechanical stresses alters both pore volume and size distribution (Krümmelbein, 2007, Zhao et al., 2010, Horn and Peth, 2011), as well as it affects pore connectivity, with major impacts on water and air conductivity. (Fig.6)

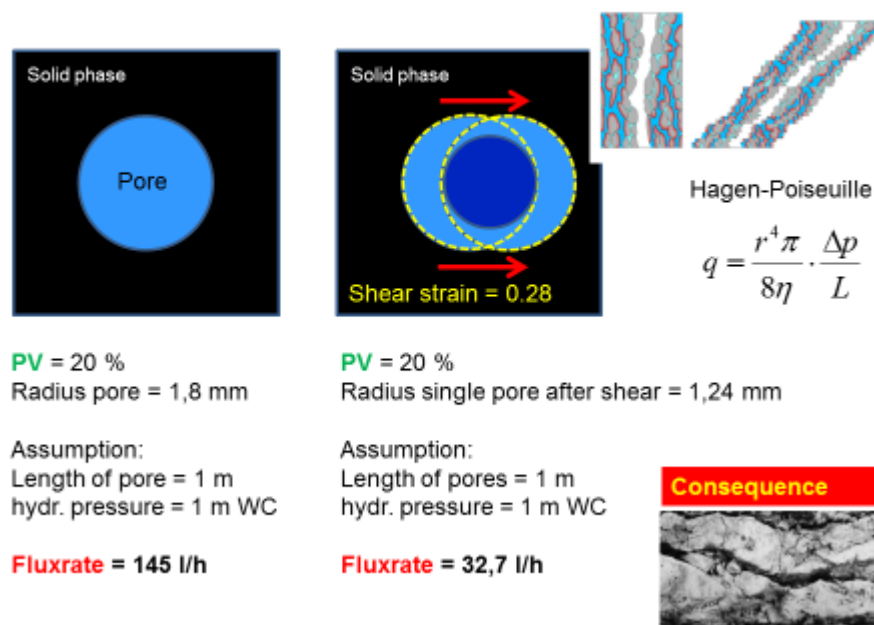


Figure 6. Effect of shear deformation on pore space dynamics and water flux

Reszkowska et al. (2011) proofed that even depending on the trampling intensity not only a drastic and mostly irreversible reduction of the hydraulic conductivity occurred especially in the topsoil but the direction dependent changes in the fluxes serve as indicator for the preservation of soil sustainability (Fig. 7).

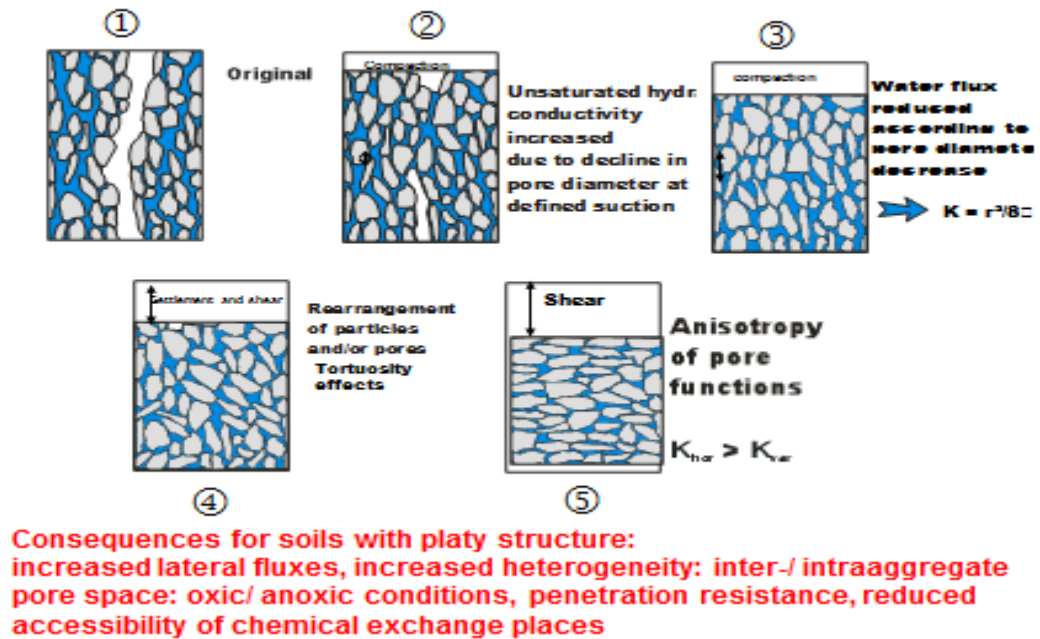


Figure 7. Stress and strain effects on hydraulic properties

Within the recompression stress range the pore size distribution and the hydraulic conductivity both remain constant as it was proved by uncounted measurements summed up in DVWK (1995,1997) directives. In the virgin compression load range, however, decreases the total pore volume, air capacity, and the saturated hydraulic conductivity even if the plant available water content partially increases at low stress application. In total are the pore system as well as the functions unstable and react flexible in this stress range.

3.3. Coupling of physical, chemical and biological processes

Soil structure properties and functions are interlinked with mechanical stresses (Fig. 8)

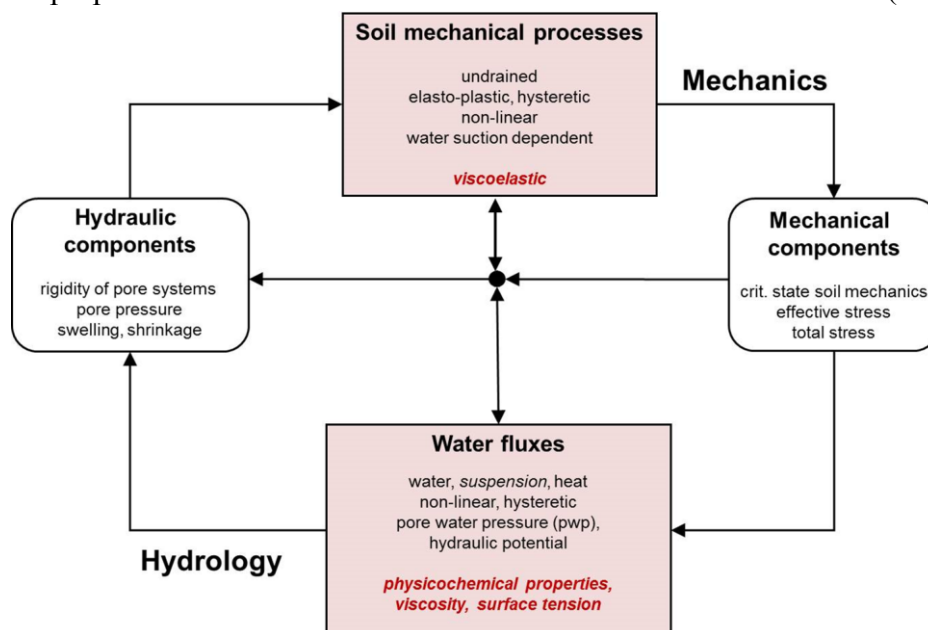
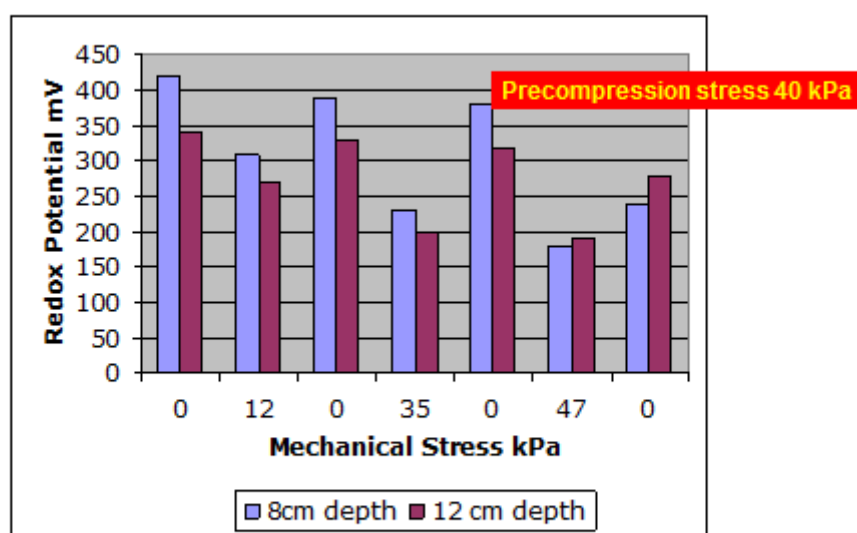


Figure 8. Coupled mechanical and hydraulic properties and processes (modified after Richards et al., 2001)

How intense these interactions also coincide with microbiological behaviour if stressed mechanically can be derived from the sink source changes of CO₂ or CH₄ emission under stress (Fig. 9). As long as the internal soil strength is not exceeded, the stress-induced decline in redox potential regains the former values after stress release, while after exceeding the rigidity of the soil structure results in a continuous and permanent decrease of the redox potential values. The strong interactions between stress application and changes in biological activity can be also derived from the changes in CO₂ emission and even in the formation and release of methane because of completely anoxic conditions in soils (Horn, 1985; Horn et al., 2009). Exceeding the precompression stress therefore also separates microbial species from their origins, which again underlines the necessity to quantify and to separate the internal strength and related permanent properties from unpredictable soil properties and behaviour in the virgin compression load range.



Cambisol Ah horizon, pH: 5.2, -60 hPa, alpine forehill pasture land, cattle herds

Data taken from Horn 1985

Figure 9. Redox Potential values as function of applied mechanical stress.

In the same context can be discussed the gas exchange with the atmosphere, the aeration of the rhizosphere and the composition of the microorganisms (oxic/anoxic) (Horn and Smucker 2005, Uteau et al., 2014, Krümmelbein et al., 2013). Doerner and Horn (2006), documented the increasing effect of stress and shear affected horizontal anisotropy on the hydraulic and gas permeability, which coincides with a retarded gas exchange and an increased proportion of e.g. CO₂ or even CH₄ in soil pores and hinders the normal population growth. If the internal soil strength is exceeded the microbial composition and activity is converted to anoxia and results even in the emission of CH₄ (Haas et al., 2016). Additionally an aggregate dependent carbon sequestration is enhanced and depends on its previous soil management or history (Wiesmeier et al., 2012). Thus, the rigidity quantified as precompression stress separates the beneficial storage and increased accessibility from the non-rigid conditions and a complete alteration of the physicochemical properties and

processes and affects not only the internal soil processes but also even the atmospheric composition.

Limitations for modelling approaches

These strong interactions and sensitive changes of soil properties and functions in relation to the amongst others mechanical, hydraulic history of soils or even soil horizons require a more general classification of such rigidity interactions also with respect to modelling approaches. Table 1 sums up the effects of soil structure in various soil horizons on properties, and options to model physical processes. Weak aggregates are very sensitive to stresses and alter the properties very intensely already at low stresses, while more advanced aggregates are more rigid and maintain their properties over a larger stress range. Consequently, the accessibility of surfaces e.g. for cation exchange processes is limited in weak aggregates and the pore system is not very rigid and can therefore not be reliably used for modelling. Very rigid soil horizons like those with polyhedral or sub angular blocks allow more reliable model predictions.

These difficulties also prevent a reliable modelling of coupled processes because these input data still is mostly unknown and require a more advanced research for process based modelling of transport processes in the Soil Plant Atmosphere continuum.

Table 1. *Effect of soil structure in various soil horizons on properties, and options to model physical processes. (Horn and Smucker, 2005)*

	property	property	property	time dependence of functions	time dependence of functions	time dependence of processes	modelling
	typical horizons	typical structure	rigidity of pore system	pore system	hydraulic properties	pore water pressure (due to compaction)	application of (existing) models
ploughed horizon	Ap	coherent	small	very high	extreme	extreme	impossible
plough pan	App	platy	extremely high	small	small	high	++
subsoil	A1 (clay depletion)	coherent	small	high	high	medium	--
	Ae (eluviation)	coherent	small	medium	high		-
	Bt (clay accumulation)	subangular blocky - prism	very high-medium	small-medium	small-medium		++
		coherent, cementation	small	small	medium		+
	Bhs (illuviation of organic compounds, sesquioxides)	prismatic-polyhedral	medium-high	medium	high		-
	Bv (weathering, oxidation)	coherent	small - high (glacial till extremely high)	high small	very high medium	small	--
	C (parent material)	solid (rock)	high	extremely small	very small		+ (++)

Conclusions

Soil structure formation results in increased mechanical strength, which can be quantified both by the precompression stress or the parameters of the Mohr Coulomb failure line. The higher the internal soil strength the more pronounced is the rigidity of the pore system and the more elastic react soils within the recompression load range.

The elasticity is replaced by plastic irreversible soil deformation within the virgin compression load range and causes additional changes in soil functions.

Physical, chemical, and biological properties show an identical pattern with mostly constant values within the recompression load range and alterations beyond the precompression stress value. Thus, within the recompression load range behave the soils primarily elastic, while in the virgin compression load range (beyond the precompression stress) react soils with a plastic deformation and a corresponding intense change in physical, chemical and biological properties and functions.

All corresponding modelling attempts are therefore limited to this recompression stress range, where the rigidity assumption still holds true. As long as the soil structure remains rigid, all soil functions remain and can guarantee corresponding ecological functions and even maintain an extended biodiversity.

The main parameters and functions of the hydraulic, gas, or heat flux under given potential gradients must be added by the rigidity information in order to finally obtain in future work also a more complete insight in the effect of Land-use Management Systems on Coupled Hydraulic Mechanical Soil Processes Defining the Climate-Food-Energy-Water Nexus”

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The Challenges Emanating from Soil Utilization Practices and the Levels of Conservation Education and Awareness Among Rural Farmers in Nigeria.

P.O. Simeon*, N. J. Apaji* and H. E Jijingi*



**Department of Soil Science and Land Resources Management,
Federal University Wukari, P.M.B 1020, Wukari Taraba State - Nigeria
Corresponding Author: P.O. Simeon, e-mail: posimeon@yahoo.com*

Abstract

Sustainable Development is the utilization of resources to ensure the creation of materials and/or facilities/ devices that improve the well-being of man and his habitat in such a way and manner that the resources continue to be available for exploitation over a long period of time. However, many interacting factors of both nature and human activities continue to constitute great obstacles in the realization of the goal. This paper is aimed at adding to the awareness campaign in the aspects of soil utilization practices and the level of conservation awareness amongst our rural farmers who are responsible for over 70 % of local arable field crops produce. This work is an original scholarly research/ inquiry based on review of related pedagogic and didactic materials as well as observations in visits to farming communities. The results reveal soil degrading practices and low level of conservation awareness resulting from poor education (literally and practically) by government and /or private agencies occupied with sustainable development drive. The paper ends with useful suggestions that can impact positively on the awareness level and better practices by the rural farmers.

Key words: utilization, creation, habitat, conservation, resource, obstacles.

Introduction

Sustainable Development is the utilization of resources to ensure the creation of materials and/or facilities/devices that are gradually more advanced with the objective of improving the well-being of man and his habitat/living environmental conditions in such a way and manner that the resources continue to be available for exploitation and advancement over a long period of time. Development means the gradual growth of something so that it becomes more advanced, stronger, etc. (Oxford Dictionary).

Land is one of the principal factors of production and upon it man depends for great proportion of his needs for housing, food and water supply, materials for industries, minerals and energy resources amongst many others. And soil is the topmost layer of land. The thickness of this layer of soil depends on so many factors and therefore varies globally and

within national territory, that is, from place to place according to natural and human factors. These factors are soil formation factors and the factors/conditions the formed soil is subjected to and which can promote its development or degeneration or stagnation and deterioration. For the rural farmers in Nigeria, soil means so much to them for their agricultural production and the construction of their houses, store houses and shelters for their domestic animals.

Soil utilization practices in arable crops production are mode of bush clearing (which may involve soil disturbance), tillage practices, application of fertilizers to enhance soil fertility, application of herbicides to curb weeds, management of post-harvest field (exposed soil) and harvest remains, method of irrigation and sources of irrigation water, selection of types of crop and sequence of cultivation, shifting cultivation and bush fallowing, land ownership system and its effect on erosion control and proper land/soil development, etc.

The major challenges to the attainment of sustainable development goals is the exploitation of soil (land) for agricultural production, especially, arable crop production, and the management of wastes generated in farming/rural communities. The soil is very precious to the rural farmers even though they are unable to understand how tied they are to the soils and also unable to appreciate the need for its sustainable development by adopting good and proper (corresponding) conservation practices, which should include the stoppage of piece-meal land holding. We know that this small holdings results from excessive fragmentation on the basis of inheritance cultural practices which have taken place over the years and which have the tendency to continue as family trees grow bigger and bigger.

Reasonable level of western education and knowledge of the “modus operandi” of modern agricultural inputs management nitty-gritty together with the exigencies and climate change social and technical dynamics are lacking in the rural farming communities. The ill-deployment and poor commitment of agricultural extension agents under the Agricultural Development Programme (ADP) have not helped matters. All these foretold challenges confronting the rural farmers could have been reasonably mitigated if the level of education on conservation and the level of conservation awareness were conscientiously promoted and created respectively among rural farmers in an efficient Nigerian socio-economic development consciousness rather than the over-whelming greed and self-centeredness government agents are presently employing to pursue programmes that ought to be very well-meaning to the populace. We have witnessed agricultural extension agents applying for local farmers acidic reaction fertilizer like urea on acidic very sandy-loam soils which further increases the acidity of the soil in maize farms because of the limitation of the brand of industrial fertilizer available and the inadequate knowledge of the agents. There is widespread continuous burning of the field in the dry seasons, especially in areas where the local populace hunt for bush rats and rabbits and thus leaving the soil exposed to the intense heat and high temperature of the dry season resulting in rapid degradation of the soil. There is rampant and/or widespread poor tillages that continues to turn over only the top 5cm depth of the soil year after year. We have seen silty pond water being used year after year for local dry season irrigation farming of vegetables and which over time have led to the silting of the soil pores and consequently flooding and surface run-off causing erosion instead of infiltration of

water. We have also observed polythene materials being indiscriminately dumped around rural settlements and blown by winds all over with the possibility of being buried inside the soil over time leading to soil deterioration since they are not easily degraded while negatively affecting the drainage capacity of the soil.



Plate 1. Land clearing by burning to hunt for bush rats and rabbit and left bare throughout the dry season. Most especially in the Middle Belt zone of Nigeria.



Plate 2. Poor disposal of wasted polythene material littering the surface and which would damage soil on incorporation.



Plate 3. Mixed cropping on poor soil tillage practice and polythene materials blown into the farm by wind.

Great majority (almost 100 %) of the agricultural extension agents sent to assist rural farmers are secondary school leavers and majority of which did not even obtained the mandatory five (5) credit pass in their final examination and as such are not knowledgeable enough for adequate soil management skill despite the trainings being given to them from time to time which centres mostly on the lighter principles of crop and livestock management.

According to Hugh (2009), “there is great need for more real soil conservation teaching in our school from lower grades of both public and private schools on up through the colleges and universities “Demand for pertinent information in the form of suitable teaching materials have mounted correspondingly. Farmers’ bulletins, technical bulletins and non-technical publications, motion pictures, photographs, exhibits, the agricultural press, radio, and television have been widely utilized to present facts and provide the latest information on sound conservation farming. Economic stability develops from good soil used intelligently and protected from erosion and unnecessary wastage of rainfall by excessive runoff. Basically, the economic stability of both city and rural populations depends on how farmers use and care for their land”.

Ross, W.A in the editor’s forward of Hugh, 2009, stated that “few are able to visualize the benefits which would accrue if all America’s soil could be adequately protected by sound soil conservation measures. The successful combination of human and basic land resources determines progress. **Economic stability and the wise use of soils are inseparable and soil lost cannot be restored.**

Hugh (2009) stated further that we cannot restore the soil after it is lost but can hold and improve what is left. According to him, top soil scattered over the bottom of the ocean cannot be returned to the fields and pastures from whence it came by any practical operation available to man. The implication of this is that, we must learn to hold, keep or guarantee the safety of the soil while it is still with us or within our reach. Thus, soil is an irreplaceable resource (Hugh, 2009).

According to Chude (2011) most countries worldwide are facing different magnitudes of food crises largely due to conflict and natural disasters, including droughts and flood linked to climate change. He stated further that the intergovernmental panel on climate change (IPCC) predicted that in the next decades, billions of people, particularly those in the developing countries (including Nigeria) will experience dramatic changes in rainfall patterns that will contribute to severe water shortages or flooding, and rising temperatures that **will cause shifts in crop growing seasons**. Changes in mean rainfall and temperature as well as the increase in extreme events will affect crops and livestock farming, forestry as well as fisheries. Many impacts, such as increased land degradation and soil erosion, change in water availability; biodiversity loss, etc will need serious attention.

According to Stephen (2011), the threats to the sustainable use of soil that led to the formation of European Soil Protection Strategy are soil sealing (land taken through urbanization, industrialization and transport), Erosion, Decline in Organic Matter, Contamination, Loss of Biodiversity, Compaction, Salinisation, Flooding and Landslides. He

said “these threats arise because we expect the soil to perform a range of functions each of which is important for human wellbeing and the environment:-

1. Production of biomass through agriculture and forestry;
2. Protection of the ground water and the food chain against contamination, and maintaining biodiversity by filtering, buffering and transportation activities;
3. Preservation of the gene reserve, which is by far the largest of the globe, and 3 - 4 times larger within the soil than that above ground, thus providing a very significant habitat;
4. Provision of the physical basis for infrastructural development such as housing, industrial production, transport, dumping of refuse, sports, recreation and others;
5. Serve as a source of raw materials, furnishing gravel, sand, clay and other materials for infrastructural development for example;
6. Preservation of the geogenic and cultural heritage by concealing and protecting archaeological and paleontological remains”.

Generally, any soil is at its best when it is still in its natural state under the protective cover of natural vegetation which is lost the moment man begins to make use of the land on clearing the vegetation. In this situation, the soil is exposed to the danger of deterioration, desiccation and accelerated erosion. (Areola *et al.*, 2006)

According to Ojeniyi (2014), Research has shown that land clearing and tillage are indispensable in crop production while experiences indicated that tillage enhances oxidation of organic matter and release of nutrients whereas it degrades soil quality in the long run if not well managed. The use of destructive land clearance and tillage practices should be discouraged because they easily dispose the soil to erosion by water or wind. One of such is the scraping of large quantities of top soil and heaping them together in dome-shapes as mounds; a practice that exposes the land to erosion and eventually leads to loss of the humid top soils which can in turn lead to ultimate destruction of soil structure and productive capacity of the land.

“Eco-Physical Perturbation associated with land preparation in most of the maize-cassava production area, when not properly handled, often leads to irreversible environmental degradation with attendant low crop yield. **Consequently, appropriate land and soil management practices are not only critical in optimizing soil productivity but also a prerequisite for sustainable land use.** In south eastern Nigeria and other parts of the humid tropics, the most predominant soil management practices include fallowing and tillage. Soil fertility regeneration under the traditional farming system relies on the length of fallow period and type of vegetation. However, with increasing population fallow period have become drastically reduced to the point that it can no longer keep the soil fertile” stated Omenihu, *et al.*, (2014).

Table 1. Major Crops Grown in Nigeria by Region.

Crop category	Southern zone	Middle belt zone		Northern zone
Cash crops	Cocoa	Beniseed	-	Groundnut
	Rubber	Rubber	-	Cotton
	Oil palm	Oil palm	-	Beniseed
Food Crops	Yam	Pigeon pea	Yam	Sorghum
	Cassava	Sweet potatoes	Cassava	Millet
	Maize	Cocoyam	Maize	Rice
	Rice	Plantain	Rice	Soya beans
	Cocoyam	Sorghum	Millet	Pigeon pea
	Plantain	Cowpeas	Soyabeans	
	Sweet potatoes	-	-	Potatoes

Source: Asadu, 2012

“Smallholder farmers who use simple production tools, simple techniques and bush-fallow cultivation contribute two-thirds of farm production” in Nigeria (Asadu *et al.*, 2012). Above, the middle belt and the northern Nigeria which experiences a dry season of five to seven months (during which less than 25 mm of rainfalls) lies mostly in the Sudan Savanna and the semi-arid Sahel zone. The staples in these areas are millet, cowpeas and drought-resistant variety of sorghum, and maize (which is cultivated in wetter area. The principal commercial crops are cotton and groundnut. Early dry season irrigated crops like onions, tomatoes and other vegetables are also cultivated.

Materials and Methods

Study Area

Nigeria is a country lying between Longitude 3⁰ and 15⁰ East of the Greenwich Meridian and Latitude 4⁰ and 14⁰ North of the Equator. Thus, it is within the tropics with tropical climate, vegetation and soil. The soil range from poorly weathered thin layered and semi-arid brown type in the northern part, deep highly weathered and leached sandy/lateritic type in the mid-south (including the south-eastern parts) and alluvial type in the coastal areas. The climate is characterized by progressive drier conditions from the south towards the north. The rainfall, constituting the key climatic variable, creates alternating wet and dry seasons. In most areas, the peak of the rainy season occur through most of the northern parts in august, when the south west monsoon wind from the Atlantic Ocean covers the entire country (Asadu *et al.*, 2012; Iloeje, 2003).

Certain working tools and agricultural practices are closely tied to the ethnicity and locations of the rural farmers. And these working tools and practices are capable of having influence on the soil, especially the tillage tools/implements

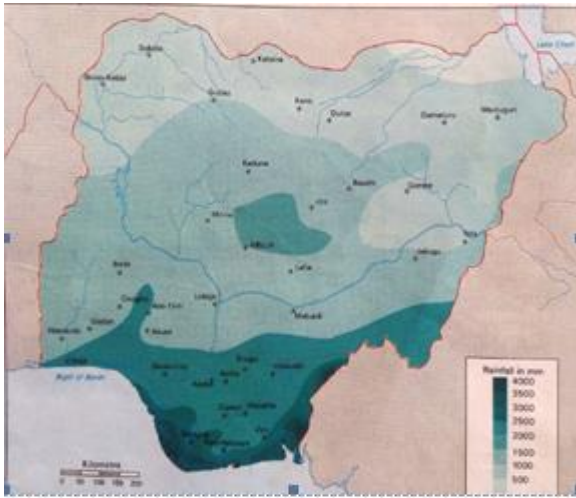


Figure 1. Map of Nigeria Geology
Source: Senior Secondary Atlas, 2004

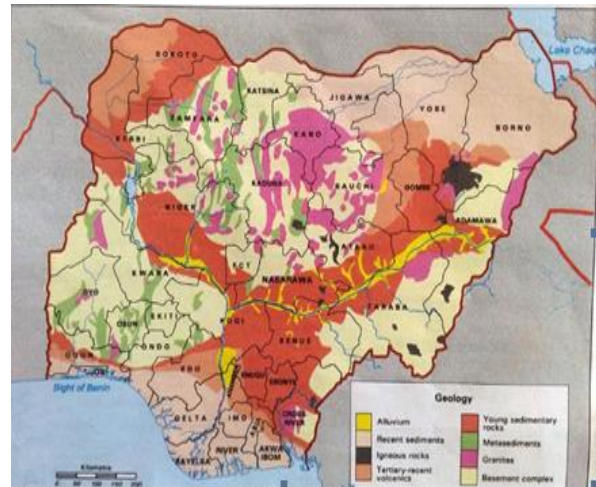


Figure 2. Mean Annual Rainfall Map of Nigeria
Source: Senior Secondary Atlas, 2004

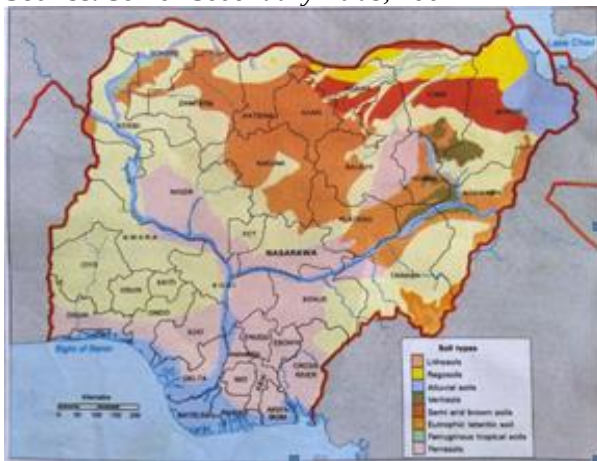


Figure 3. Map of Nigeria Soils
Source: Senior Secondary Atlas, 2004

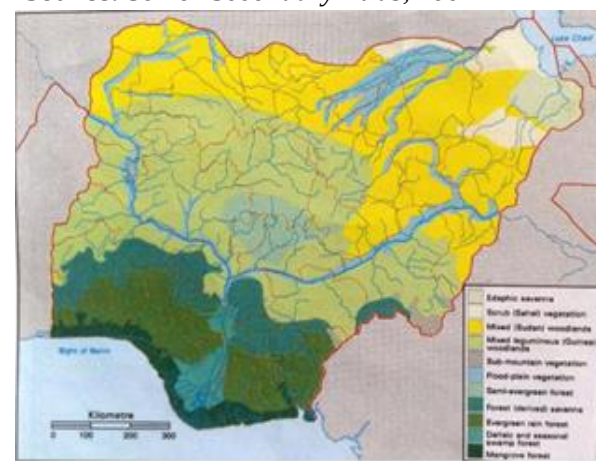


Figure 4. Vegetation Map of Nigeria
Source: Senior Secondary Atlas, 2004

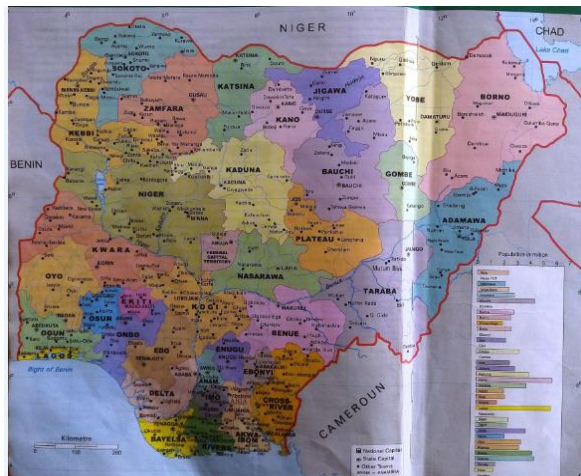


Figure 5. Map of Nigeria 2004 political/
Administrative
Sources: Senior Secondary Atlas, 2004



Figure 6. Map of Nigeria Showing the Major
Ethnic Group
Sources: Senior Secondary Atlas, 2004



Figure 7. Food Crops Map of Nigeria
Source: Senior Secondary Atlas, 2004



Figure 8. Map of Nigeria; Livestock
Source: Senior Secondary Atlas, 2004

Method

The scholarly inquiry is based firstly, on review of related literatures and secondly on personal visitations to and the observations in several rural farming communities in Nigeria. These include Mayo-Belwa and Ngure in Adamawa State; Dikwa and Gumsuri in Borno State; Irokhin and Ekiadolor in Edo State; Pindiga and Duku in Gombe State; Akokwa and Ohaji-Egbema in Imo State; Kachia and Kwello in Kaduna State; Gwamba and Bagizza in Kebbi State; Oja-odan and Meko in Ogun State; Ila and Ifetedo in Osun State; Gwande and Yerimawa in Sokoto and Rafinkada and Garin Dogo in Taraba State. The choice of locations and states was influenced by accessibility, the rural nature with farming activities and need for spread with the study area. All three authors were involved in area closest to their homes.

The basic arable and plantation crops husbandry practices and materials of rural houses are similar in all locations. These visits were over a reasonable period of time and for purposes that were not originally for this present work. All sections of the country have large rural farming communities with over 70% of food locally produced coming from the rural farmer

Results and Discussion

The observations were based on the negativity of the equipment and materials implored in the basic practices associated with soil utilization and on whether the farmers were actually aware of what they ought to do and what they ought not to do against the backdrop of their level of education and access to educating materials and agents/agencies (whether governmental or non-governmental). The practices included land tenure system, bush clearing, farming system, tillage and seedbed preparation, application (type, mode and time) of chemicals (herbicides, fungicides/pesticides and fertilizers, etc), harvesting and collection of main produce, post-harvest soil management, housing materials, (types and sourcing), erosion (water and wind), land/soil sealing (limit in the size of land/soil available for farming) and soil conservation practices if any.

The major observations are:

1. Application of chemicals (inorganic fertilizers, herbicides, fungicide/pesticides) without regard to the compatibility between soil solution reaction (pH) and the active ingredient in the chemicals. Thus, there is no matching of chemicals with the type/nature of soil once they are effective against the target and tolerated by the crops.
2. Every rural farmer in Nigeria scraping top soil for building of houses and other forms, and the use of tall strong grasses for roofing as well as construction of mat for compound fencing is common in the northern part (Plates 6, 7 and 8).
3. Clearing of land is mainly by trees felling, shrubs and grasses (if fresh) by slashing with matchets, allowing to dry up and setting of fire (burning process) (Plate 1).
4. Regular fragmentation of land in the course of sharing the properties of dead adult male amongst the children leading to increase in the piece-meal land-holdings. In some case farmers hold small pieces of land of less than one (1) acre (0.4 hectares) scattered in so many locations far from each other.
5. Mixed cropping is most common in the southern part and inter-cropping of new crop towards the harvesting of previous is common in the northern and middle belt parts of the country (Plate 3).
6. Severe gully erosion features wiping out rural farming communities in Garin-Dogo (Taraba State), Auchu axis in Edo State and several location in the souther eastern while sheet erosions are rampant and prominent in the southern state (Plate 4 and 5).
7. Regular re-heaping of the very friable/loose sandy or powdery and structure less top soil to make heaps, ridges and beds for planting is common using big head local hoes and in few communities there is use of ill-prepared tractor-disc plough and tractor-disc harrow aggregates that scrap only the surface with poor turning of scraped soils that leaves the grasses and remains not buried and top soil pulverized instead of being buried. These occur mostly in the central and northern part since tractors aggregate tillage is hardly employed by rural farmers in the wetter southern part, where the use of small head long handle West African and West Indian hoes rampant (Plates 3, 11 – 15).
8. No properly planned crop rotation in space and time (moving crops around in certain number of plots/farmland from one cropping season year to another). It is either mono-continuous cropping which is common in the central and northern parts or shifting cultivation plus bush fallowing which is common all over the country. Unfortunately the length of fallow has dropped to only 2-3 years (cropping seasons) due to insufficient availability of land caused by increases in population and decline in land for farming
9. Poor disposal of wastes from houses or homes and livestock rearing units. These waste could have been useful in compost manure making that could have aided soil fertility boosting (Plate 2, 6 and 10).

10. Poor and low level of tillage incorporation of crops post-harvest remains and grasses remains into the soil.
11. Application of phosphorous and potassium fertilizers in the form of NPK at the wrong time and use of wrong method as well as wrong depth.
12. No mulching of the exposed surface in row crops to avoid excessive evaporation in the northern part and to promote percolation and avoid run off and quick flooding in the wetter southern part. All over the country the soil are left bared (exposed) during the dry season which of course is longer in the northern part with more intense sunshine (Plate 1).
13. Selling of soil made bricks which promotes soil lost (Plate 7). If about two-thirds of farm production is held by the local/rural farmers, one cannot overestimate the magnitude of the worrisome soil utilization practices and the bleak the future seems to hold in view of the rapidity with which land available for agriculture is decreasing.
14. Poor levels of education and conversation awareness in rural areas, as shown by the table 2 below:-

Table 2. *Level of Literary Education of the Local Rural Farmers in Percentage (%) among 10 (ten) farmers interviewed*

S/No	Location(s) Visited represented by State	Non- Primary		Primary		Secondary		Ordinary diploma equivalent		Degree	
1	2	3		4		5		6		7	
		No.	%	No.	%	No.	%	No.	%	No.	%
1	Adamawa	5	50	2	20	1	10	1	10	1	10
2	Borno	8	80	1	10	1	10	0	0	0	0
3	Edo	2	20	3	30	2	20	1	10	2	20
4	Gombe	5	50	2	20	2	20	1	10	0	0
5	Kaduna	5	50	3	30	1	10	1	10	0	0
6	Kebbi	8	80	1	10	1	10	0	0	0	0
7	Ogun	3	30	3	30	2	20	2	20	0	0
8	Osun	3	30	3	30	3	30	1	10	0	0
9	Sokoto	8	80	1	10	1	10	0	0	0	0
10	Taraba	3	30	3	30	2	20	1	10	1	10
Average % (all states)		5.0	50	2.2	22	1.6	16	0.8	80	0.4	40

Table 3. *Level of Conservation and Sustainable Development Goals Awareness, in Percentage (%) among 10 (ten) farmers interviewed outside of routine shifting cultivation Practice*

S/No	State Visited	0 – 5 %		6 – 10 %		21 – 40 %		41 – 70 %		71 – 100 %	
1	2	3		4		5		6		7	
		No.	%	No.	%	No.	%	No.	%	No.	%
1	Adamawa	9	90	1	10	-	-	-	-	-	-
2	Borno	9	90	1	10	-	-	-	-	-	-
3	Edo	9	90	1	10	-	-	-	-	-	-
4	Gombe	9	90	1	10	-	-	-	-	-	-
5	Kaduna	9	90	1	10	-	-	-	-	-	-
6	Kebbi	9	90	1	10	-	-	-	-	-	-
7	Ogun	9	90	1	10	-	-	-	-	-	-
8	Osun	8	80	2	20	-	-	-	-	-	-
9	Sokoto	9	90	1	10	-	-	-	-	-	-
10	Taraba	9	90	1	10	-	-	-	-	-	-
Average % (all states)		8.9	89	1.1	11	-	-	-	-	-	-

Table 4. *Level of Access to regular educating information in easy to follow medium and easy to understand language among 10 (ten) farmers interviewed*

S/No	State Visited	Radio		Television		Agric. Ext. Agent		Agric. Shows + Motion Pictures		Newspaper Write-up		Agric. Bulletins	
1	2	3		4		5		6		7		8	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	Adamawa	8	80	0	0	2	20	-	-	-	-	-	-
2	Borno	8	80	0	0	2	20	-	-	-	-	-	-
3	Edo	5	50	3	30	2	20	-	-	-	-	-	-
4	Gombe	7	70	0	0	3	30	-	-	-	-	-	-
5	Kaduna	7	70	1	10	2	20	-	-	-	-	-	-
6	Kebbi	6	60	2	20	2	20	-	-	-	-	-	-
7	Ogun	7	70	1	10	2	20	-	-	-	-	-	-
8	Osun	7	70	1	10	2	20	-	-	-	-	-	-
9	Sokoto	7	70	0	0	3	30	-	-	-	-	-	-
10	Taraba	5	50	1	10	4	40	-	-	-	-	-	-
Average % (all states)		7.1	71	0.9	90	2.4	24	-	-	-	-	-	-



Plate 4 and 5. Gully Erosion Devastating Community and destroying the Land
Sources: Personal Field Work, 2015



Plate 6. Houses built from top soil and roof from grasses that could have been used for manure and mulching and soil littered with waste polythene materials



Plate 7. *Bad tillage of top soil to mould block for housing*



Plate 8. *Part of Old Kano showing houses build with top soil*



Plate 9. *Soil left bare after Scraping the top soil*



Plates 10. *Poor disposal of wasted polythene material littering the surface and which would damage soil on incorporation*

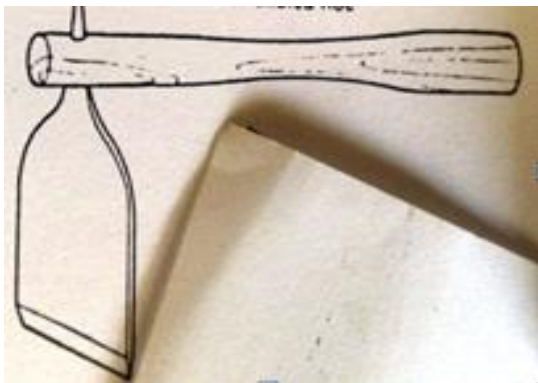
Plates 11 – 15. *Some common tillage tools/implement which do not promote proper soil tillage*



11. *Big head hoe which can not promote realization of modern tillage requirement*



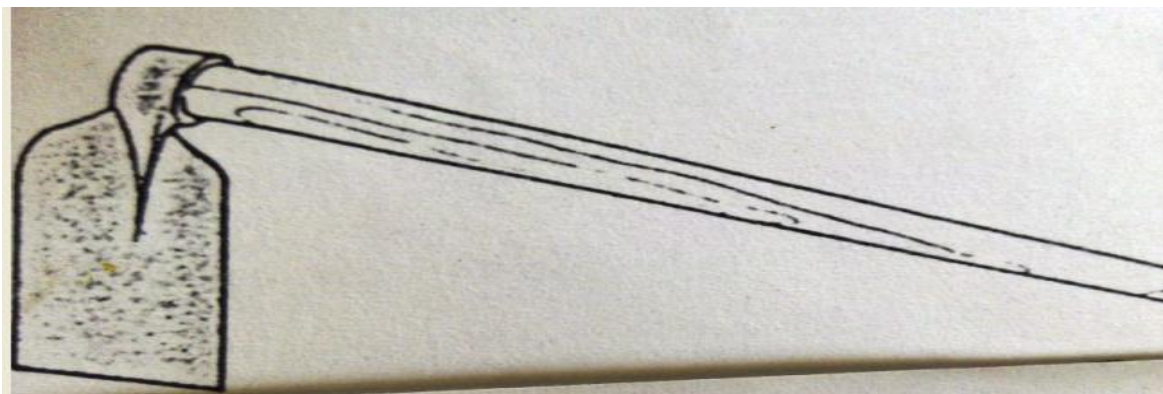
12. *Disc Harrow with improper adjustments of working organs and depth*



15. *Short handle hoe*



14. *Disc plough with improper adjustments of working organs and depth.*



15. West African hoe which cannot promote realization of modern tillage requirement

The results (shown in words and photos) have pointed out clearly the unwholesome soil utilization practices among rural farmers. It is up to the government and its agencies charged with the responsibilities of agricultural and rural development and sustainable development goals to conscientiously start working for the purpose of socio-economic advancement of the Nigerian State.

Further attention must be drawn to the fact that the moment the natural vegetation covering the soil is cleared and man begins to use the land, it is exposed to three types of danger namely **Deterioration**, **Desiccation** and **Erosion**.

The deterioration involves loss of soil fertility (marked by fall in humus and nutrients content coupled with breakdown of soil structure). A deteriorated soil will exhibit a fall in crop yields and nutritional quality; increase growth of weeds if used as farmland; decreases resistance to erosion, and reduction in the ability of crops cultivated on it to resist pests and diseases.

Desiccation is the progressive drying out and hardening of soil body due to prolonged exposure to high temperature (intense insolation). The evidence of this process in soil, is the occurrence in the soil profile of iron stone gravel; laterite crusts and clay pans. The surface can become so hard that little water can infiltrate into it. This situation generates excessive water run off thus causing serious erosion. This is common in sudan and sahel savanna where overgazing and annual bush burning expose the land to intense isolation. Research has shown that the preventive measures include provision of adequate water through irrigation, adequate cover for the soil on farmlands; planting of cover crops; controlled grazing of the land and control of bush burning.

The manner of soil utilization can promote erosion by water or wind. The erosion by water can be **Splash** (break up of soil aggregates by the impact of rain drop such that the soil particle fly out in all directions); **Sheet** (removal of soil in thin layer by runoff water over broad gently sloping surface) and **Gully** (which creates deep gorges or valleys which divide land surface and hinder movement and the cultivation of land). The sheet erosion, is the most widespread of the water erosion and it affects the humus, clay and nutrients which are found in the top soil.

So, much soil for agriculture is lost when farmers scrap top soil for construction of houses for themselves and domestic animals and storage facilities. The wrong applications of chemicals have led to soil pollution, soil underground water pollution and have also affected soil solution reaction (pH). How do we apply urea to an acidic/slightly acidic reaction sandy-loam soil? It will only make the soil more acidic which might become toxic to crops with less tolerance of such soils.

The non-corresponding tillage practices and piece-meal ownership of land by individuals do not make it easy to design and manage comprehensive erosion control or drainage measures in most of the rural farming communities. There is need for more aggressive soil conservation education and awareness creation among rural farmers in Nigeria.

Conclusion

It is obvious from the fore stated that the mode of utilization of soil by rural farmers in Nigeria substantially negates the dictates of sustainable development. And unless something is done urgently the worrisome situation will continue to worsen with severe impact on food and raw materials supply and eventually the socio-economic stability of the country. The challenges are still surmountable at the level they are now and the challenge is on all of us.

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Roles of *Leucaena leucocephala* (Lam.) on Sandy Loam Soil pH, Organic Matter, Bulk Density, Water-Holding Capacity and Carbon Stock Under Humid Lowland Tropical Climatic Conditions

Patrick S. Michael

Department of Agriculture, PNG University of Technology

PMB, LAE, MP 411, Papua New Guinea.

Corresponding Author: Patrick S. Michael, e-mail: patrick.michael@pnguot.ac.pg



Abstract

Leucaena (*Leucaena leucocephala* Lam.) trees planted in alley cropping or established on fallowed farms by natural means contribute significantly to soil health and productivity by influencing various soil properties. In this study, the effects of *L. leucocephala* (Lam.) on sandy loam soil pH, organic matter content, bulk density, water-holding capacity and carbon stock were investigated under humid lowland tropical climatic conditions in Papua New Guinea (PNG). Soil samples were collected from 60 cm deep piths dug out from 1 m and 2 m away from the base of the legume trees. The control soil samples were collected from adjacent grassland dominated by *Imperata cylindrica* (L.), 10 m away from the legume trees. In all the piths, soil samples were collected from the 0-20, 20-40 and 40-60 cm profiles. The results showed presence of the legume trees acidifies the soil (lowers pH), lowers surface soil organic carbon, improves the water holding capacity within the surface soils and helps improve bulk density, ideal for root growth. Comparatively there was more carbon in the surface soil of the grassland than under the legume trees. In most tropical regions, grasslands are often set a blaze for various land uses and the high carbon content is a potent source of CO₂ emission, contributing to the greenhouse gases (GHG) in the atmosphere. The low carbon stock measured under the legume trees means reduced emission of CO₂ when burnt and more benefits for the sandy loam soil. This study has implication for management of sandy loam soil using *L. leucocephala* (Lam.) under humid lowland tropical climatic soil conditions.

Keywords: *Leucaena leucocephala* (Lam.), sandy loam soil, pH, bulk density, SOC, water-holding capacity, carbon stock

Introduction

In the humid tropics, most farm soils are allowed to fallow for a given period of time following crop production to allow the farm to revert to natural vegetation. When the farm soil has reverted, the natural vegetation established, depending on the duration of the fallow period and agro-climatic (and environmental) conditions, would range from a few dominant grass species, such as *I. cylindrica* (L.) to a combination of fast growing legume trees species, such as *L. leucocephala* (Lam.), *Gliricidia sepium* (Jacq.), *Anthonotha macrophylla* (Beauv.), *Longocarpus griffonianus* (Baill.) and other common shrubs. The grasses have poor nutrient content and therefore have limited potential to help improve the conditions of the farm soil. Some grasses may even thrive on whatever nutrient that was left from the previous crop production system, leading to soil degradation and loss of fertility.

Compared to the grasses, legume trees are rich in nutrients and are able to replenish depleted soils. Legume trees such as *L. leucocephala* (Lam.) and *G. sepium* (Jacq.) have symbiotic associations with bacteria, e.g. *Clostridium* and *Astobacta*, that are capable of trapping atmospheric nitrogen which is returned to the soil when the trees die. For this reason, many legume trees are used in alley crop worldwide (Giller and Wilson, 1991). In addition, legume trees are known to improve soil organic matter, stimulate soil biological activity, improve soil structure, increase soil aeration, increase soil water-holding capacity and even make tillage operations easier (Kang *et al.*, 1999; Sanginga *et al.*, 1992; Doube, 1997; Warren and Zou, 2002; Imogie *et al.*, 2008). Not only these, litter of legume trees contributes to improvement in cation-exchange capacity, carbon-nitrogen ratio, pH and other biological, chemical and physical soil properties (Rilling *et al.*, 2007; Robinson *et al.*, 1993; Wardle, 2002; Wardle, 2005).

The importance of legume trees on soil biological, physical and chemical properties is widely established but studies in the tropics, especially under humid lowland tropical climatic conditions such as PNG, under various land use systems is limited. We have reported in a recent study conducted under such climatic condition that fallow improves the productivity of peanut (*Arachis hypogea* L.) under continuous cropping (Aipa and Michael, 2018a). Another study following that showed that fallow increases the threshed yield of rice to 8 tonnes per hectare compared to the yield of other LUS such as manure application and crop rotation, ranging from between 8 to 8.5 tonnes per hectare (Aipa and Michael, 2018b).

We have shown from these studies that the changes in soil carbon, nitrogen, phosphorus and potassium contents were small following a period of 4 months of fallow and was dominated by three dominant grass species, *I. cylindrica* (L.), *Saccharum spontaneum* (L.) and *Rottboellia cochinchinensis* (Lour.) (Aipa and Michael, 2018a). What was not clearly established from this study is the importance of the legume trees that dominate the farm when under fallow. Therefore, this study was conducted to investigate the roles of *L. leucocephala* (Lam.) on soil pH, organic matter content, bulk density, water-holding capacity and carbon stock. Total porosity was further estimated to assess the effects of the plants on the water-holding capacity of the sandy loam soil.

Materials and Methods

Description of study site: The study site is shown in Figure 1 as per Aipa and Michael (2018a). The farm (6°41'S, 146°98'E) is located at an altitude of 65 m above sea level with a mean annual rainfall of up to 3,800 mm, which is fairly distributed throughout the year. Average daily temperature is 26.3 °C, with an average daily minimum of 22.9 °C and an average daily maximum of 29.7 °C. Annual evaporation (US Class A pan) is 2,139 mm and rainfall exceeds evaporation in each month. The climate is classified as Af (Koppen), i.e. a tropical rainy climate that exceeds 60 mm rain in the driest month.

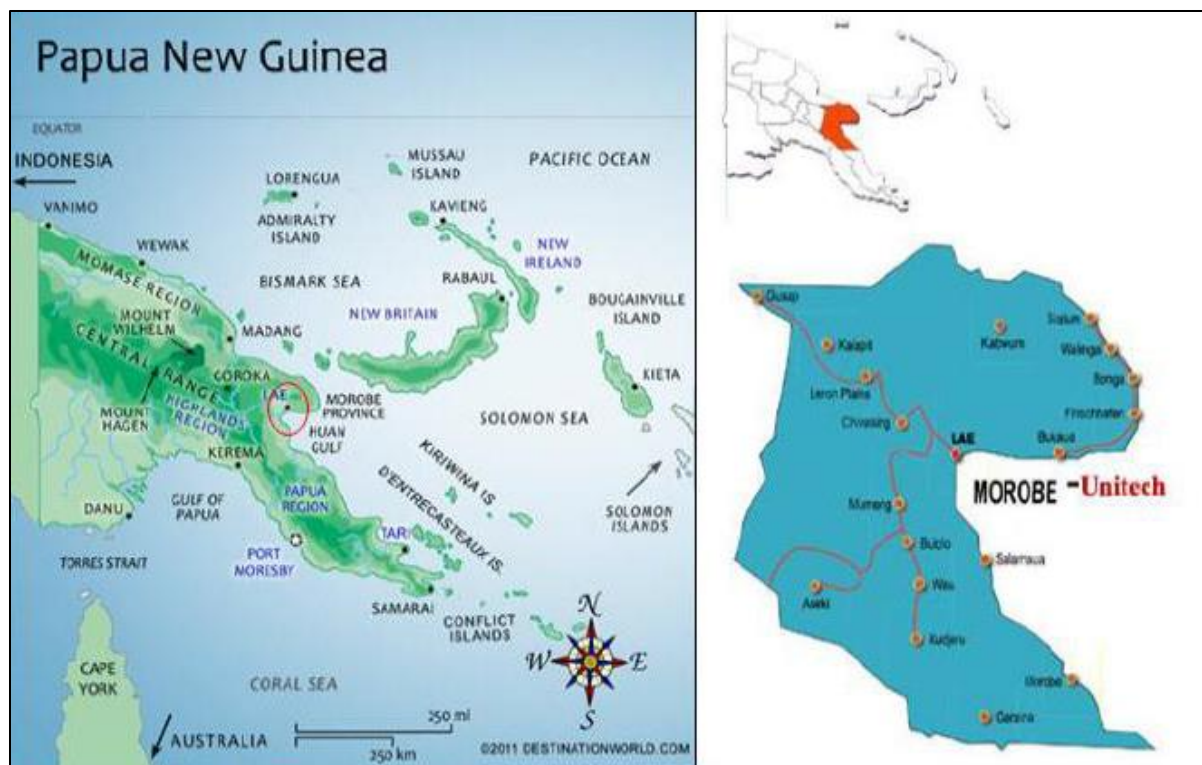


Figure 1. Map showing the location of the study site in Lae, Morobe Province, PNG

The soil at the experimental site is well drained, derived from alluvial deposits and is classified as a sandy, mixed isohyperthermic, Typic Tropofluents (Soil Survey Staff, 1999) or Eutric Fluvisol (World Reference Base, 2015) (Aipa and Michael, 2018a). The *L. leucocephala* (Lam.) trees and the grassland got established naturally when under fallow for nearly 10 years.

Sample collection: To collect the soil samples, a stripping method was used to dig three 60 cm deep piths. The first pith was dug 1 m away from the base of the legume trees, the second pith was dug from 2 m away from the base, and the third from a grassland. The grassland was 10 m away from the base of the legume trees and dominated by *I. cylindrica* (L.). The samples taken from the grassland were treated as the control. At each spot, e.g. in the grassland, 1 m or 2 m away, a single pith was dug. These piths were marked out into 0-20, 20-40, and 40-60 cm profiles using a 1 m ruler and triplicate samples (spadesful) were taken from each profile for analysis. The samples for bulk density calculation were taken using cores. All the samples were put in labeled air-tight plastic bags with sealed ends and placed in several buckets before taking them to the laboratory for measurements and analysis (Figure 2). A total of 180 samples, 72 samples (3 reps x 3 profiles x 4 parameters x 2 sampling locations) from under the legume trees and 36 samples (3 reps x 3 profiles x 4 parameters) from the grassland (as control) were collected.



Figure 2. (a) Digging 60 cm piths, (b) sampling, (c) collecting samples in labeled buckets, and (d) sample photo showing the density of the legume trees of the study site

Measurements: The soil samples collected were used to determine soil pH, soil organic carbon (SOC) content, water-holding capacity (WHC) and bulk density (BD). These were done at the University Analytical Services Laboratory, PNG University of Technology, PNG. pH was measured using the standard dilution (pH meter (1:5 soil: water w/v)) method (e.g. Michael *et al.*, 2012; 2015, 2016, 2017). The soil organic carbon content (%) was analysed using the weight loss-on-ignition method (Schutle and Hopkins, 1996; Michael *et al.*, 2015; 2016). A 5 g of the soil samples was placed in a crucible by weighing and heated in a muffle furnace for 12 h at 105 °C to remove moisture (W_f) and combusted again at 375 °C for 17 h (F_w), cooled for 2 h and weighed. The soil residue in the crucibles was combusted in a muffle furnace at 800 °C for 12 h, cooled for 2 h and reweighed. In studies like this, the SOC content is estimated by multiplying the carbon value by a factor of 1.72 (Aipa and Michael, 2018b). Based on this, the SOC contents (%) were calculated as:

$$\text{SOC (\%)} = [((W_f - F_w) \div W_f)100] \div 1.72 \quad \text{Equation 1}$$

where SOC is the SOC content determined using the weight loss-on ignition method and 1.72 is the conversion factor. The conversion factor was used to convert the organic matter content to organic C, assuming there was 58% C in the organic matter. The size of the C stock in each profile was calculated as the sum of the individual C fractions (%) $\times$ g cm⁻³ $\times$ profile depth (cm) and expressed as percentage.

The water-holding capacity (WHC) was estimated as per Michael (2015) by setting soil samples at 100% water-holding capacity after soaking in water and draining through a filter overnight. These were weighed for the wet weight (Ww) and dried in an oven at 105 °C for 48 h and reweighed to obtain the oven dry weight (ODw). WHC was determined as:

$$\text{WHC (\%)} = [(Ww - ODw) \div ODw] 100 \quad \text{Equation 2}$$

Bulk density (g cm^{-3}) was calculated by oven drying of the cores at 105 °C for 48 h followed by re-weighing (Aipa and Michael, 2018a). The oven dry weights were divided by the volume of the core and kept as the BD. Total porosity was determined as per Landon (1991):

$$P = \left(1 - \frac{BD}{d}\right) 100 \quad \text{Equation 3}$$

where P is total porosity (%), BD is bulk density and d is particle density equal to 2.65 g cm^{-3} .

Results and Discussion

Soil pH under various land use systems are affected by factors such as organic matter content, aeration, microbial activity and soil water status. pH in turn affects oxidation and reduction of minerals, release and mobility of minerals, and stability and availability of nutrients (Reddy and Patrick, 1977; Deshmukh, 2012). Under natural soil use conditions, more leaf litter and dead plant matter fall close to the base of plants within the surface, whereas in the deeper soil are limited to dead roots and root exudates (Michael *et al.*, 2017).

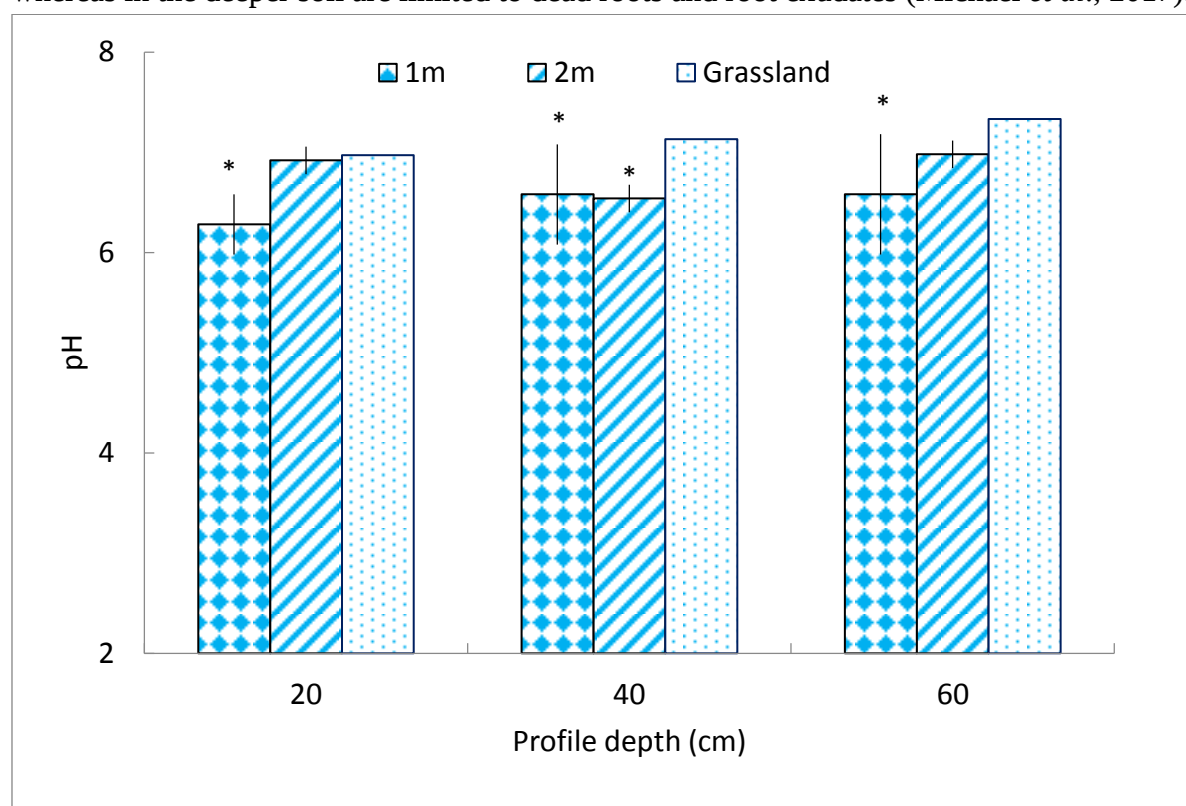


Figure 3. Soil pH of soils 1 m and 2 m away from the base of the legume trees at different profiles. The values are mean $\pm$ s.e. of three replicates ($n=3$). An asterisk indicates significant difference ($p<0.05$) between the legume trees and the grassland at the same depth

The changes in pH measured are shown in Figure 3. Compared to the grassland soil pH which was near 7 units throughout the profiles, presence of the legume trees acidified the soil near the base, the changes in pH ranging from between 6.3 to 6.6 units within the surface to deep. pH of the soil further from the base (2 m) within the surface (0-20 cm) was higher and similar to that of the grassland, but at the deeper profiles (20-40 cm and 40-60 cm) were lower (Figure 3). These types of variability in pH of sandy soils under different land use have been reported (Enakiev *et al.*, 2018, Michael and Reid, 2018; Michael, 2015). When the pH was low in the presence of the legume trees, generally SOC content was small (Figure 4), WHC was between 20-60% (Figure 5) and BD was less than 0.4 g cm^{-3} (Figure 6). In most soils, decomposition of plant matter and release of anions and organic nitrogen lead to an increase in pH as microbes act on the resources (Michael *et al.*, 2016). The opposite happens when nitrification takes place, resulting in acidification reaction and low pH. We have shown that organic matter addition in strong acidic soil ($\text{pH} < 4$) raises pH to well above circumneutral level (e.g. Michael *et al.*, 2015, 2016, 2017). In general, presence of the legume trees acidified the soil, either near the base within the surface or 2 m away at deeper soils. Olujobi (2016) reported a pH of 7.1 within the 15-30 cm surface of a sandy loam soil with *L. leucocephala* (Lam.), compared to the pH of 6.6 units observed within the 20-40 cm (Figure 3). The small decrease in pH by 0.5 unit observed in the current study resulted from leaching of cations and nitrification of the organic nitrogen from the decomposition of plant litter. In other studies, legume trees were generally seen to increase surface soil pH by increasing Ca^{2+} level and reduction of exchangeable H^+ (Drechsel *et al.*, 1991; Madukwe *et al.*, 2008).

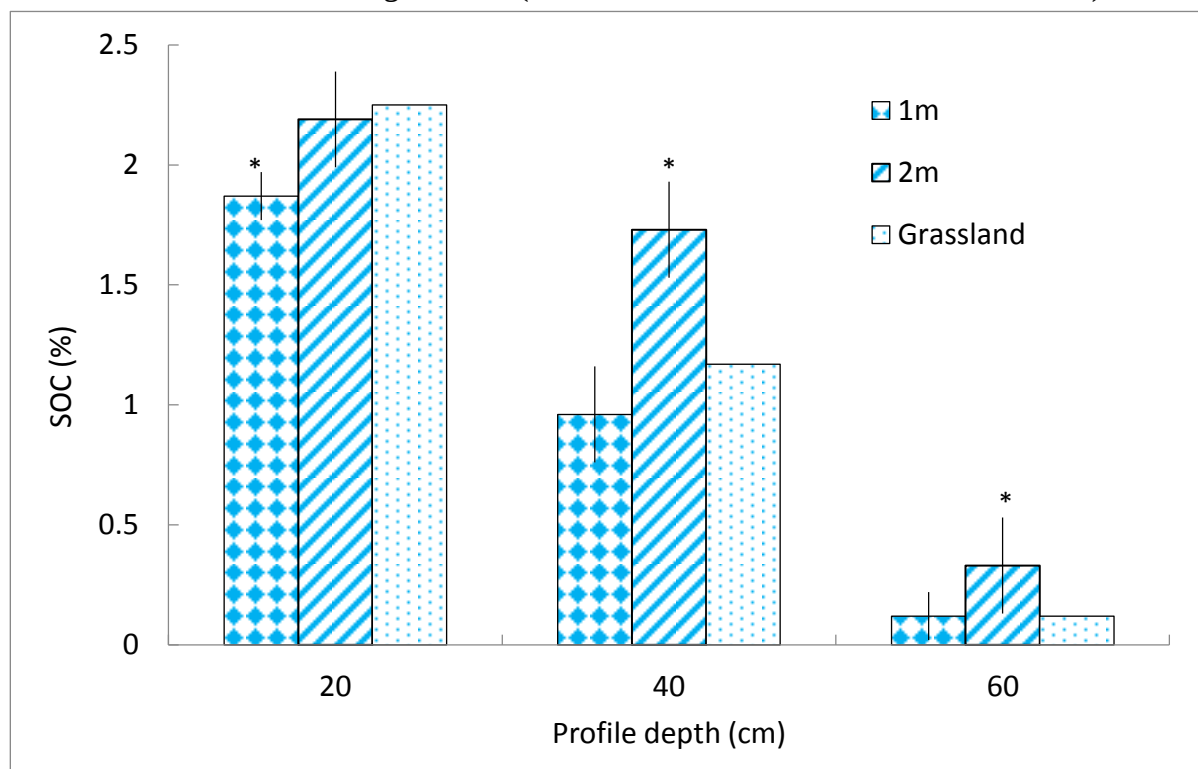


Figure 4. Soil organic carbon content of soils 1 m and 2 m away from the base of the legume trees at different profiles. The values are mean $\pm$ s.e. of three replicates ($n=3$). An asterisk indicates significant difference ($p < 0.05$) between the legume trees and the grassland at the same depth

The SOC contents and the changes in C stock are shown Figure 4 and Table 1, respectively. In all soil types, SOC is important for various biological, physical and chemical processes that are needed for soil health and productivity (Bais *et al.*, 2006; Bell *et al.*, 2005; Bossuyt *et al.*, 2004; Michael, 2018). For example, SOC regulates pH, redox, cation-exchange capacity, enhances water-holding capacity (Kang *et al.*, 1990) and aerates soils (Imogie *et al.*, 2008). The SOC contents near the legume trees (1 m) and 2 m away within the surface soils (0-20 cm) were small, ranging from between 1.9-2.2%. Generally, high SOC content resulted in small porosity, indicating organic matter availability reduced pore spaces. For example, when the grassland SOC content was 150%, the porosity was reduced by nearly 43%.

In the deep soils (20-40 cm and 40-60 cm), the SOC contents were much smaller and nearly the same except that a small increase was found at the 40 cm profile in the soil 2 m away from the base of the legume trees (Figure 4). This probably is due to high turnover of organic matter from the legume trees as well as the grass that got established further from the base of the legume trees as a result of low canopy. These results agree with Olujobi (2016) who reported SOC contents of 1.7% within a 15-30 cm profile under *L. leucocephala* (Lam.). A similar observation was made in this study. The SOC contents were decreasing from the surface to the deep soils, more so in the grassland. For instance, the SOC content decreased from 2.3% at the surface to 0.1% at deep. When the organic matter in the SOC was converted to C using Equation 1, a significant decrease was observed under the two *LUS* (Table 1).

Table 1. The C stock (%) was decreasing from the surface to deep soils

<i>LUS</i>	Sampling location	Profile depth (cm)		
		0-20	20-40	40-60
Legume trees	1 m	8.0±0.2*	8.0±0.3*	1.8±0.2*
	2 m	9.0±0.3*	14.0±0.2*	5.0±0.2*
Grassland	Single spot	152.0±0.3	34.0±0.2	7.0±0.3

An asterisk indicates significant difference ($p < 0.05$) between the legume trees and the grassland at the same depth.

The effects of C stock on pH, WHC and BD are shown Table 2. The general trend shown is that as C stock was decreasing, soil pH was decreasing, WHC was above 50% and BD was $< 0.5 \text{ g cm}^{-3}$. A similar loss in SOC content by 10.1% (1.8/17.8 from Table 1) was observed in the soil closer to the legume trees. For example, 1.9% SOC content within the surface (0-20 cm) decreased to 0.12% at deep soil (40-60 cm) (Figure 4), a loss of C stock by 4.1% ($0.12/2.95 \times 100$). These results demonstrated that the C stock was high within the surface, probably due to high turnover of organic matter. In deep soils, the C stock decreased (Table 2), indicating the sources of carbon addition there were limited. These results agree with the common knowledge that most of the organic matter from live plants end up within the surface soils (Michael, 2017). Sandy soils have poor water retention and require significant amount of organic matter to be present to hold water. The results of this study showed that *L. leucocephala* (Lam.) has the potential to improve surface SOC content and the C stock (Table 1) sufficient ($> 55\%$) reduce porosity and hold water to support growth of plants.

The legume tree is perennial; therefore turnover of organic matter at deeper soils is expected to be small as more roots are alive then dead to provide sufficient organic matter,

whereas the grass species is expected to turnover organic matter (e.g. dead roots) more quickly being an annual, building up the SOC content and the C stock. In soils with smaller plants, organic matter accumulation from senescent plant material is small but much quicker, resulting in much higher SOC content, making them an important source of energy for the sandy soil. In the tropics, most of the grasslands are subjected to frequent fires, making the high C stock in the grassland a potent source of CO₂ for greenhouse gas (GHG) emission. This study showed that having legume trees in grasslands would offset this GHG emission problem by the lowering the C stock in soils (Table 2).

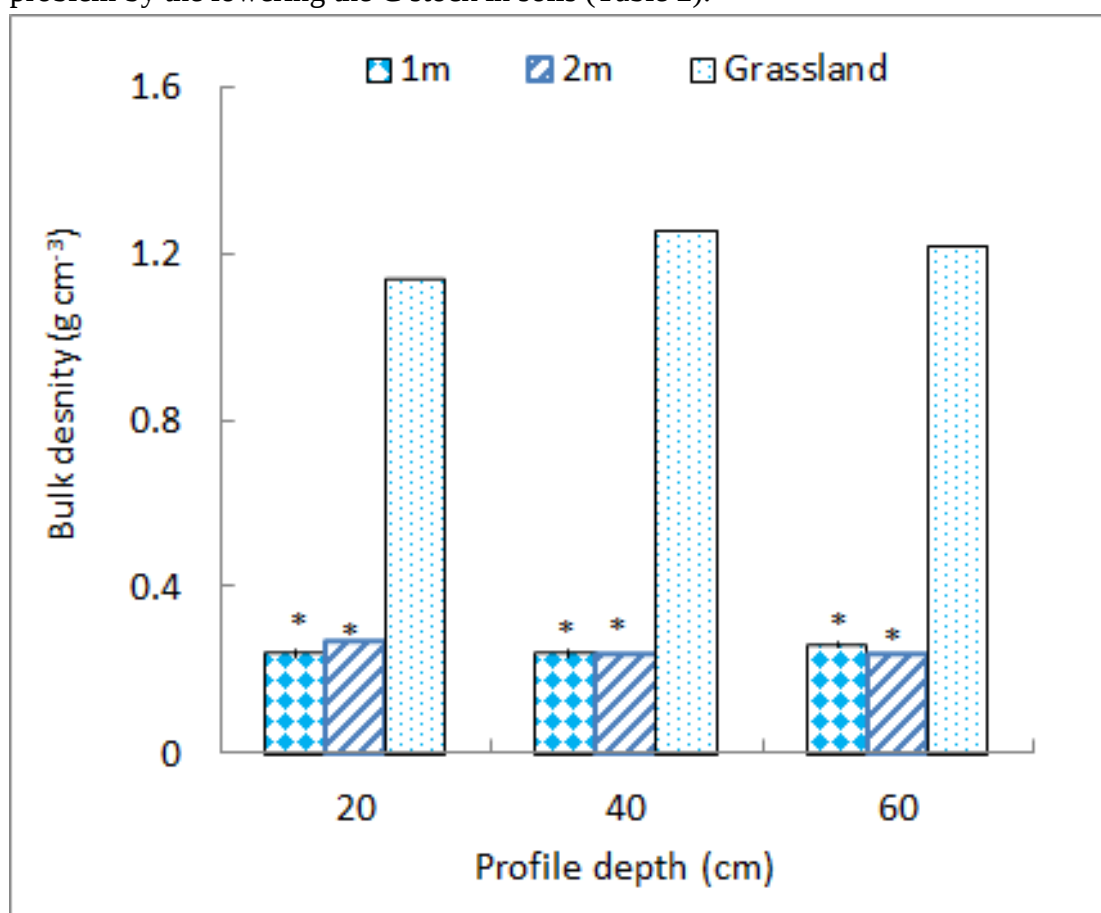


Figure 5. Bulk density of soils 1 m and 2 m away from the base of the legume trees at different profiles. The values are mean $\pm$ s.e. of three replicates ($n=3$). An asterisk indicates significant difference ($p<0.05$) between the legume trees and the grassland at the same depth

Bulk density is a measure of soil structure and in most soils increases with depth. The BD measured in the grassland was near 1.2 g cm⁻³ (Figure 5), consistent with 1.4 g cm⁻³ of Aipa and Michael (2018a). In the presence of the legume trees, BD decreased to below 0.5 g cm⁻³, near and further from the base of the legume trees. In the same sandy soil, when rice was continuously cultivated, rotated with maize or fallowed for 4 months, BD remained nearly unchanged (Aipa and Michael, 2018a), the BD being same as that of the grassland soil of this study. These results indicate that BD is strongly affected by the changes in pH, SOC content and the WHC. For example, BD was small when WHC (Figure 6) or pH (Figure 3) was small. The general trend in BD observed ranged from less than 0.5 g cm⁻³ in the presence of the legume trees to 1.4 g cm⁻³ in the grassland, showing the BD was ideal for optimum root growth (Eche *et al.*, 2013). A decrease in C resulted in increase in BD (Table 2). As expected,

total porosity was high in the surface soil and smaller at the deep soil (Table 2), supporting the common knowledge root sizes is bigger within the surface soils and smaller at deep soil as roots branch out. The porosity of the grassland was fairly constant, ranging from between 57% within the surface to 54% at the deep soils. This means the high SOC content in the grassland was sufficient to reduce the pore spaces in the sandy loam soil, and the small roots and the shallow rooting systems of the grass plant were not enough to increase porosity.

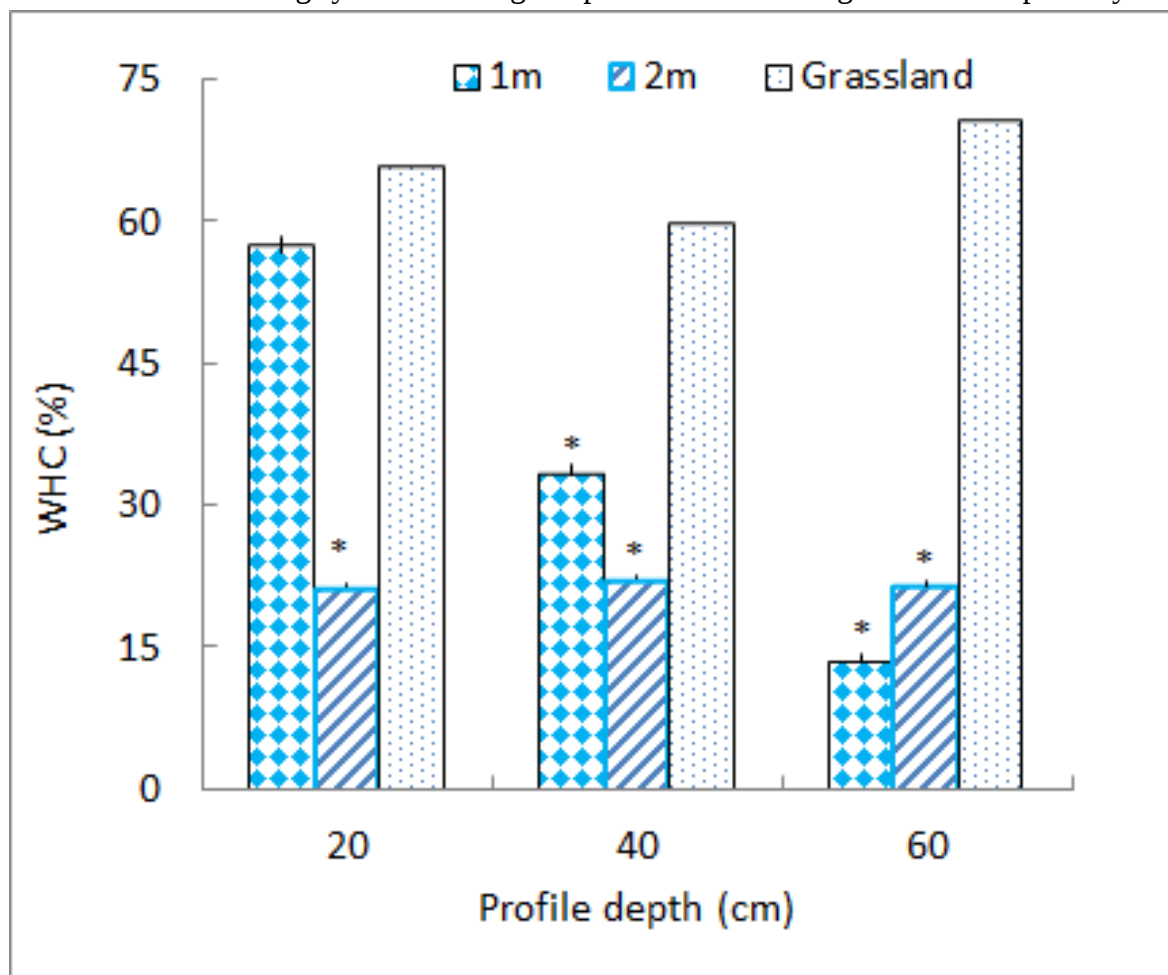


Figure 6. Water-holding capacity of soils 1 m and 2 m away from the base of the legume trees at different profiles. The values are mean $\pm$ s.e. of three replicates ($n=3$). An asterisk indicates significant difference ($p<0.05$) between the legume trees and the grassland at the same depth

The variability in WHC measured is shown in Figure 6. In the grassland, WHC was fairly constant throughout, ranging from between 60-75% (Figure 6). Compared to that, WHC was near 60% within the 0-20 cm soils 1 m away from the base of the legume trees. This decreased to near 30% within the 20-40 cm soils and further decreased to below 15% at 60 cm. These results did not show a clear relationship between BD and pH but as SOC content was high, WHC is high and as it decreases, WHC decreases. For example, within the 0-20 cm soil, WHC was the highest (Figure 6), corresponding to the highest SOC content of 1.9% measured within the same profile (Figure 4).

The relationship that exists between WHC and C stock near the legume trees (1 m) is shown in Table 2. As the SOC content decreased to 0.1% at the 40-60 cm profile, the WHC

decreased to near 15%, a strong indication that SOC content affects the WHC (Figure 6). This variability was found only in the soils closer to the legume trees. Further from the base (2 m), WHC was fairly constant around 22% in all the profiles (Figure 6). These types of variability are common under natural soil conditions because the turnover of organic matter is entirely variable, dependent on the plant types, age, litter type and growth conditions etc. We observed turnover organic matter decreasing and lesser litter shed by several deep rooted plants in acid sulfate soils (Michael *et al.*, 2017).

When the variability in WHC was compared to the C stock, there was a direct relationship between the changes in WHC and the C stock (Table 2). The highest C stock of 8% corresponded to the highest WHC of more than 50%, compared to the proportionate change observed at depths. Comparatively, WHC was small in soils pH and BD were small, and was high when these were high (Table 2). For example, when the WHC was 56%, pH was near 6 units and BD was below 0.5 g cm^{-3} .

Table 2. Effects of carbon stock on soil pH, bulk density and water-holding capacity

Depth (cm)	C stock (%)	pH	WHC (%)	BD (g cm^{-3})	Porosity (%)
0-20	8.0±0.2	6.3±0.3	56±0.4	0.2±0.4	92.45±0.1
20-40	8.0±0.3	6.6±0.5	34±0.5	0.2±0.1	92.45±0.1
40-60	1.8±0.2	6.6±0.6	14±0.2	0.3±0.4	88.68±0.3

In sandy soils, water retention is poor and a significant proportion of organic matter is needed to retain soil moisture for root growth. This study showed presence of *L. leucocephala* (Lam.) lowers WHC of sandy loam soils to well below 60%, whereas presence of annual grass *I. cylindrica* (L.) helps keep the WHC above 60%. This variability resulted from the variability in SOC content measured shown in Figure 4. The possible reason for the decrease in WHC at deep soils resulted from increase in porosity caused by the bigger roots and the deep rooting systems of the legume trees (Table 2), compared to the impacts of the smaller roots and shallow rooting systems of the grass plant whose effect on porosity was near 50%. The high C stock in the surface soil in the grassland (Table 1) also resulted from the small and shallow rooting systems of the grass whose plant matter mostly accumulates within the surface soil than at the deeper soils (Table 2).

Conclusion

Under different land use and management systems in the tropics, most fallowed farmlands are dominated by perennial legume trees species like *L. leucocephala* (Lam.) and annual grass species such as *I. cylindrica* (L.). The importance of these types of plants on soil properties are often not reported from this region. This study showed presence of *L. leucocephala* (Lam.) acidified the soil, increased surface SOC content, improved the BD ideal for optimum growth of roots, and retained surface soil moisture by reducing porosity. The surface soil C stock was sufficient to support normal plant growth although was small compared to that of the grassland. During the drier seasons, fallowed farmlands with dominant annual grass are often set on fire by farmers to prepare the land for the next use. The high C stock found in the grassland under such a circumstance is a potential source of CO_2 , contributing to the GHG emission. The results showed purposive establishment of *L. leucocephala* (Lam.) in farmlands under general soil use and management system would help

improve conditions of sandy loam soil, reduces C stock to level sufficient to support good soil health and productivity and help reduce CO₂ emission during fire events. In addition, use of *L. leucocephala* (Lam.) in fallow would provide nitrogen, important for sustainable use of the sandy loam soil.

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Growth Test with *Lepidium sativum* L. for Soil Monitoring of Sites, Part of the Bulgarian National Soil Monitoring System.

Silvena Boteva*, Mariyana Lyubenova*,
Hristina Kalcheva**



*"St. Kl. Ohridski" University of Sofia, Faculty of Biology, 8 D. Tzankov Blvd., 1164 Sofia, Bulgaria

**Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, 2 Gagarin Street, 1113 Sofia, Bulgaria

Corresponding Author: Silvena Boteva, e-mail: sbboteva@biofac.uni-sofia.bg

Abstract

The publication deals with the application of *Lepidium sativum* L. biotest for the study of soils from three sites included in the National Soil Monitoring Network. There were no exceedances of the limit values of the soil indicators in the monitored sites. The obtained results presented the existence of strong correlations between the bio test seeds and sprouts development and the variation in nitrogen content and the concentration of cobalt, nickel, zinc and copper in the soil. The results of this study have shown some possibilities for *L. Sativum* L. usage in soil monitoring, especially for the influence of soil nutrient elements (nitrogen) and microelements on the plants and thus for determining soil functional capacity and ability to provide material and support services.

Keywords: soil monitoring, biotest, *Lepidium sativum* L., functional soil diagnostics, germination energy

Introduction

The National Soil Monitoring System of Bulgaria is a part of the National Environmental Monitoring System (NEMS) and includes the collection, assessment and summarization of soil information as well as the maintenance of an information system on soil conditions and its modification (Ordinance № 4, 2009). As a methodological manager, the Executive Environment Agency (EEA) develops and implements the program, maintains the monitoring network and databases, evaluates and analyzes the state of the lands and soils. In 2004 a new soil monitoring program, organized on three levels, was developed and approved by the Minister of Environment and Water. Level I - Observations (large-scale monitoring) are carried out on a regular network of 16x16 km at 397 points and provide data for the assessment of soil status by the following indicators: 9 heavy metals and metalloids, total nitrogen, phosphorus, organic carbon, active soil reaction (pH) electrical conductivity, nitrate nitrogen, total carbon and persistent organic pollutants -16 PAH, 6 PCBs, 15-chlorine organic pollutants, bulk density (Figure 1). The periodicity of observation is 5 years. Observations at Level II are concentrated to regional manifestations of degradation processes - acidification (54 polygons) and salinization (12 polygons). The erosion processes caused by water and

wind are observed through specially developed mathematical models for estimation and prognosis. Soil sealing is assessed on the basis of statistical data and mapping of land cover (Corine Land Cover Project, <https://www.eea.europa.eu/data-and-maps/>). The Observations at Level III are identified with the so-called local soil contaminations within which inventory of contaminated soil areas is carried out. The inventory is still partial and irregular, based on available data. In 2007, a special Ordinance was adopted to the EEA for the inventory and surveys of areas with polluted soil, the necessary restoration measures, as well as the maintenance of the restoration activities, and in 2016 a methodology for the preliminary and detailed surveys and the establishment of a public inventory register on areas with contaminated soil was adopted (<http://eea.government.bg/bg/nsmos/soil>). Periodicity of observations varies depending on the processes. The soil samples are tested in 15 accredited Regional Laboratories of the EEA.

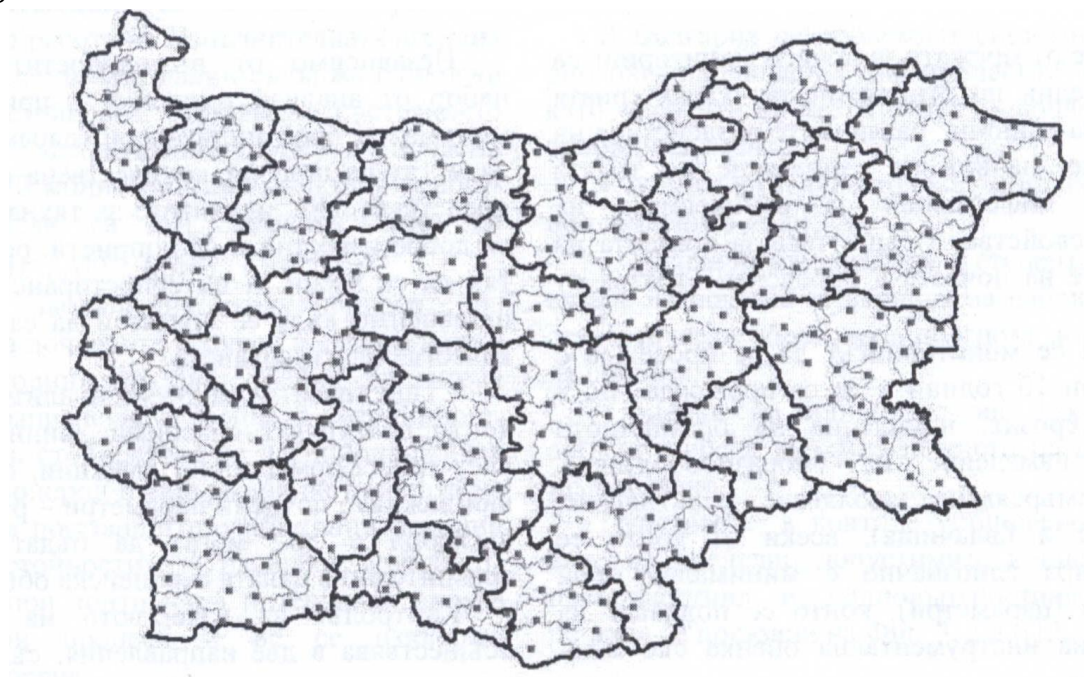


Figure 1. National soil monitoring network.

Ordinance № 3 (2008) determines the limit values of harmful substances in the soil and the requirements for soil sampling and testing to determine the content of harmful substances. According to the published soil monitoring data in Bulgaria (<http://eea.government.bg/bg/soer/2016/land-use/politiki-i-merki-za-opazvane-na-pochvite>), in the recent years there has been a tendency for reducing soil contamination and absence of exceedances of the permissible limits of pollutants. This concerns mainly agricultural land and is due to a reduction in arable land and more limited use of pesticides and fertilizers.

Bioassays with one of the most widely used test object *Lepidium sativum* L. are applied for determining the effects of soil heavy metal on its growth and germination (Pavel et al., 2013). This test object can also be used for soil monitoring as for example Gyekye (2013) recommends the use of *L. sativum* L. as a test organism for biomonitoring and detecting toxic urban soils or for monitoring the removal of PAH pollutants from soil (Maila and Cloete, 2002). Other authors (Alvarenga et al., 2008) propose the use of battery of tests for assessing the quality of soils polluted from mine activities.

The main purpose of the study is to conduct bioassays with a widely used test object in the ecotoxicology - *Lepidium sativum* L. and to compare the impact of soil samples from three monitoring sites, diagnosed as unpolluted, on physiological parameters such as: germination energy and length of the embryonic root. The other aim of the study is to investigate the relationship between the reported differences in these indicators and the established concentrations of the chemical indicators monitored in the soil. This will give additional information on the ability of *Lepidium sativum* L. to be used for soil monitoring and for diagnosing the functional capacity of the soil to provide material and support services.

Materials and Methods

Soil samples are taken according to Appendix 3 to Art.5, Paragraph 3 of Ordinance № 3 on the limit values of harmful substances in the soil (Table 1).

Table 1. *Depth of soil sampling according to the types of land use.*

Type of land use	Depth of sampling (cm)
Settlements	
Parks	0 - 10
Playgrounds	10 - 40
Industrial / production sites	0 - 10 10 - 40
Arable land	0 - 20 20 - 40
Permanent lawns	0 - 10 10 - 40

To determine the content of harmful substances in the soils, samples shall be taken and tested according to the Bulgarian or international standards and, if there are none, by validated intradepartmental methods. Sampling and testing of soil shall be carried out by accredited laboratories. The test methods used shall guarantee a detection limit for the relevant harmful substance with an order of magnitude lower than the standards under Art. 2 (Ordinance № 3, 2008).

Characteristics of the soil in the sampling areas

Soil samples from three monitoring sites in Blagoevgrad District, which are part of the first level NEMS, are tested. (Table 2).

Table 2. *Characteristics of sampling sites, soil monitoring level I.*

Settlement	Municipality	EKNM	Geographical coordinates		Sampling date	Type of land use - year 2015	Sampling depth, cm
Beslen (BE)	Hadzhidimovo	3976	41°28,112'	23°58,028'	7/10/2015	Corn field	0-20; 20-40
Breznitsa (BR)9	Gotse Delchev	6306	41°40,175''	23°39,017'	7/09/2015	Meadows	0-10; 10-40
Satovcha (SA)	Satovcha	65440	41°37,399'	24°01,096'	9/09/2015	Pasture land	0-10; 10-40

Samples taken from the territory of the village of Satovcha are Albic CAMBISOLS (FAO, 1988). They are formed on sandy clay eluvium, deluvius or proluvius, in humid climate and with the wide participation of broadleaved (beech), coniferous and mixed forests. They are distinguished by shallow soil horizon (40-80 cm), insignificant humus horizons and insignificant humus content (3-9%). The soils on the territory of Beslen village and Breznitsa village are CHROMIC CAMBISOLS (FAO, 1988). They are the most widespread soil type in Bulgaria, mainly in agricultural areas. They are characterized by a 75-120 cm soil profile and a humus horizon up to 35 cm. By mechanical composition, they have higher clay content than the typical cinnamon soils, but with less humus (2-3%). 500 ml of distilled water was added to a 50 g soil sample. Flasks are placed on a shaker apparatus for 24 hours at 160 rpm, and then the suspension is filtered and stored in a refrigerator.

Kres salad is an easy object for conducting bio-test because the seed germination and energy of germination is high and the seeds are sensitive to influences. The biotest with *L. sativum* L. is applied for toxicological and functional soil assessment. The seeds are pre-chilled for 24 hours and set for determining the energy of germination or put in distilled water for germination and growth assay. 50 seeds or sprouts (with the same size) are put at equal distances in pre-sterilized petri dishes with 18 cm diameter. The bottoms of the petri dishes are covered with 2 layers sterile filter paper (autoclaved at 120°C for 20 min) and 1 layer for the lid. The paper is carefully moistened (without air bubbles) with 10 ml (bottom) and 5 ml (lid) respectively distilled water (for the control, K) or extract from the soils from the respective depths of the three test sites (variants of the experiment). During the experiment, the petri dishes are moistured by adding the same amounts distilled water or soil extraction (BSS601-85, 2009). The germination energy (E_k) is determined on the 4th day by counting the germinated seeds in each dish and calculating in percent relative to the control. After 48 hours, the root lengths were measured in the growth test (Lyubenova et al., 2009). The results are averaged for each variant and calculated in percent relative to the control, the values of which are assumed to be 100% (ISO 7346, 1996; Lyubenova et al., 2009). Each variant and the control are placed in 6 replicates.

Log-transformations of the soil variables and response variable standardization (sprouts variables) were performed prior to the multivariate analysis to obtain normality of variance in data. Parametric (Pearson's correlation) and nonparametric (Spearman's rank order correlation) analyses were used (Statistica 7.0) to assess the traits relationships and to evaluate if the selected soil factors significantly ($p < 0.05$) explained the variation in trait values. An Analysis of Variance (ANOVA) was used to test species differences in trait means.

Results and Discussion

Most of the reported E_k values are close or exceed those of the control, i.e. soil extracts stimulate seed germination. The lowest value of E_k is recorded for 10-40 cm soil depth from the samples of Breznitsa (96.5% of the control) and the highest for the village of Satovcha in the same soil layer (104.3% of the control). For two of the sampling points the stimulative effect on E_k is better expressed in the surface soil layer: 0-20 cm for Beslen village and 0-10 cm for village of Breznitsa. Samples from Satovcha village (10-40 cm) have higher values for E_k , probably related to the organic pasture pollution (Figure 2).

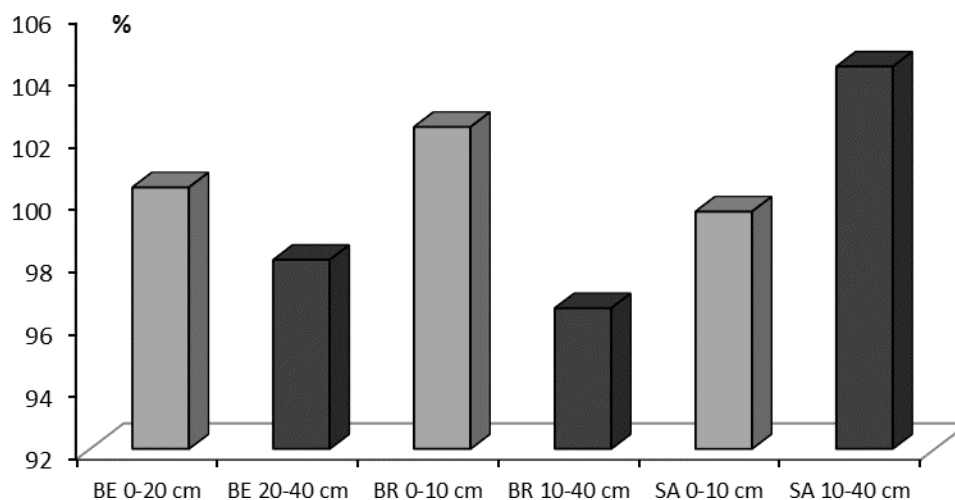


Figure 2. Number of germinated seeds, *Ek* (% of the control).

Samples from the Beslen village have the greatest length of the roots and at the same time exceeding that of the control, being 0.63 ± 0.46 cm for 0-10 cm depth and 0.65 ± 0.5 cm for 10-40 cm depth, i. e. the extract from deeper soil layer plays a more stimulating impact on the development. This is related to the type of land use and the agro-technological treatment, which on the one hand leads to faster oxidation of humus and washing of nutrients and contaminants from the surface layer. The smallest root length (0.49 ± 0.39 cm) is recorded at the Satovcha sample site for a depth of 0-10 cm. Extracts from deeper soil samples from Beslen (20-40 cm) and Satovcha village (10-40 cm) have stimulating effect on the root lengths. This effect of the extracts from the deeper soil layer is probably due to the soil treatment in the first case and organic contamination in the second. For the tested soil from the site in the village of Breznitsa, which is covered by grass vegetation, the trend is opposite (Figure 3).

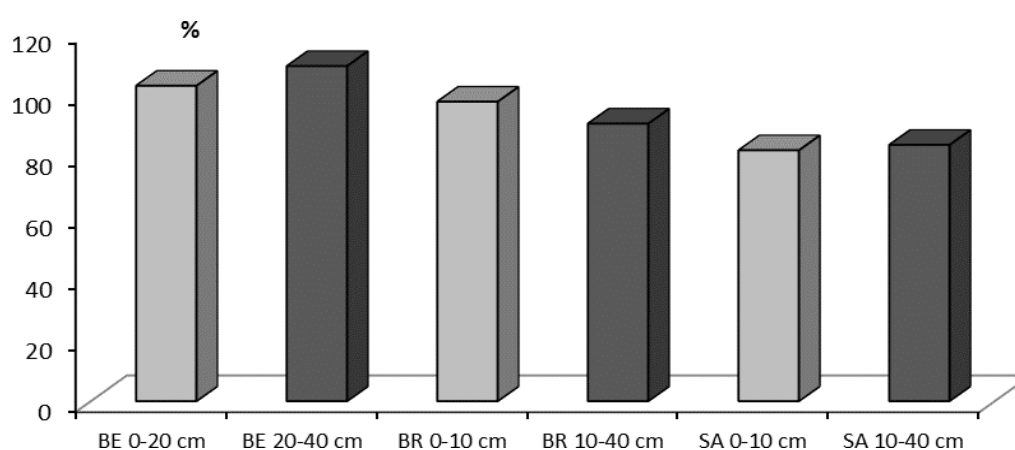


Figure 3. Length of roots of biotest in different variants (% of control).

The results of the ANOVA analysis show differences in the mean values of *Ek* and the root lengths of the sprouts between the sampling stations ($p = 0.0005$, ANOVA, F-test, Fig 4A) and soil layers (Figure 4B) are significant.

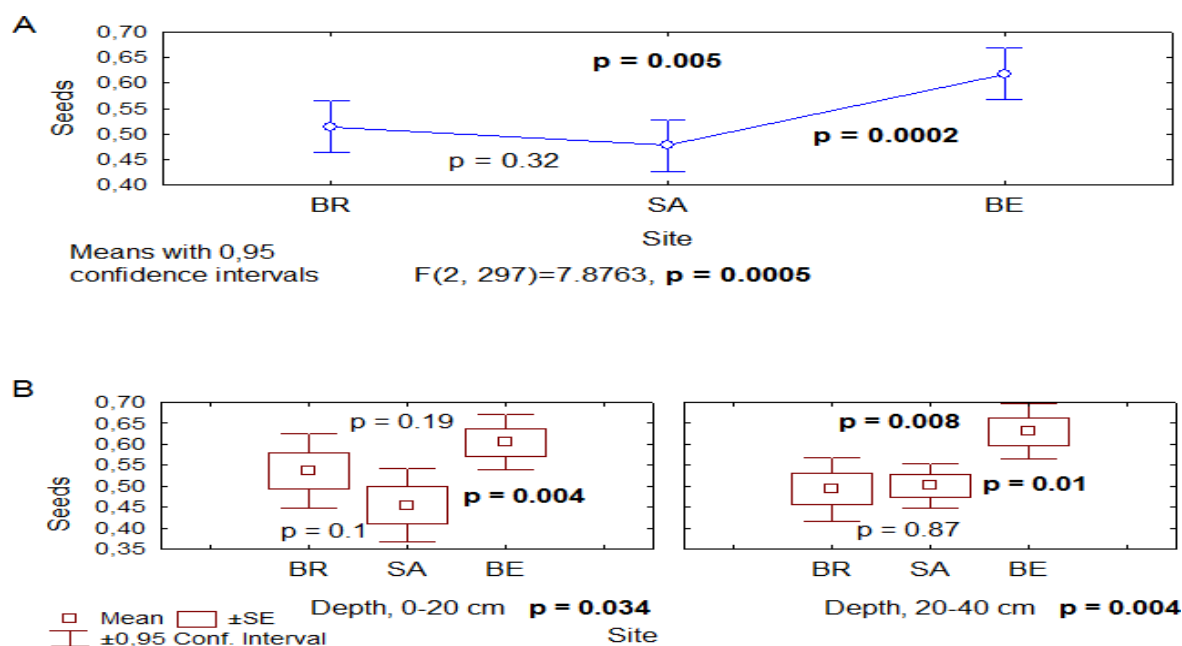


Figure 4. ANOVA *F*-tests (with given *p*-values) showing the differences of the seeds development between 3 sites (villages Brestnitsa- BR, Satovcha - SA and Beslen - BE) (A) and for each of the two sampling depths, 0 -10 (20) cm and 10 (20) - 40 cm, in the same sites (B).

The soil chemical analysis from the three sampling points in 2016 do not exceed the limit values of the indicators, which is in accordance to Ordinance № 3 (2008).

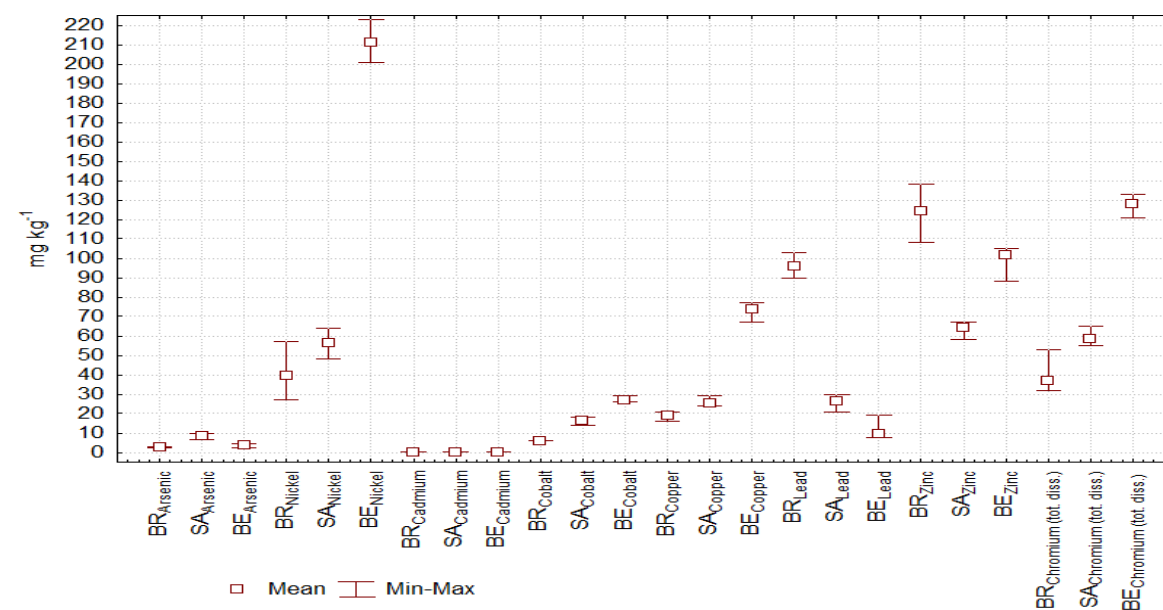


Figure 4. Average values of metals concentration (mg.kg⁻¹) with their variance (Executive Environmental Agency, 2016)

According to the Spearman's nonparametric and Pearson's parametric tests for the three studied sites and the soil layers, there is a positive correlation between the Ek and the length of the root of the biotest and Kjeldahl nitrogen; to the level of confidence is the negative correlation with the total phosphorus in the soils from the village of Satovcha and

TOC for BR_{0-10cm} (Table 3). Studied parameters of the seeds treated with soil extraction from the surface layer at the site in Beslen village and the concentrations of cobalt have positive correlation, and those from the surface layer at the point in the village of Satovcha and the concentrations of cobalt and copper are close to confidence. The positive correlations between the studied parameters of the seeds treated with soil extracts from the surface layer at the sampling points in the villages of Breznik and Satovcha and the concentrations of nickel and zinc are significant or to the level of significance. The negative correlation between the studied parameters and conductivity for point BE, as well as with pH in CaCl₂ for BE_{20-40 cm} are also close to the confidence level. Correlation coefficients vary from 0.99 to 1.00. The determined very strong correlations show that the reported change for the seed test and shoot development is related to the variation in nitrogen content and the concentration of cobalt, nickel, zinc and copper in the soil.

Table 3. Significant or to the level of significance correlations between the parameters studied and soil characteristics

Sampling Site / Soil layer	Soil parameter	Corelation coefficient, r	P values
BE _{0-20 cm}	Cobalt	1.0000	0.0000 perfect positive correlation
	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation
BE _{20-40 cm}	pH in CaCl ₂	-0.9946	<u>0.0664</u>
	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation
BR _{0-10 cm}	Nickel	0.9995	0.0203
	<u>Total organic carbon (TOC)</u>	-0.9885	<u>0.0965</u>
	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation
BR _{10-40 cm}	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation
SA _{0-10 cm}	<u>Cobalt</u>	0.9930	<u>0.0752</u>
	Zinc	0.9986	0.0334
	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation
SA _{10-40 cm}	Kjeldahl nitrogen	1.0000	0.0000 perfect positive correlation

Conclusion

Based on the obtained results, we could conclude that soil extracts stimulate seed germination in most cases. Ek was better expressed in the surface soil layer for Beslen and Breznitsa sampling stations probably due to soil treatment in the first case and organic contamination in the second. Samples from Satovcha have higher values for Ek in deeper soil layers, probably related to the organic pasture pollution.

Although there is no exceedance of the soil indicators limit values, the variations in energy germination and root length by sites, soil depth and nutrients concentrations are obtained. The strong correlations between the seed germination and sprouts development and the variation in nitrogen content and the concentration of cobalt, nickel, zinc and copper in the soil are expressed. The conducted experiments present some of the possibilities for the application of biotests in the soil monitoring, which could complement monitoring with functional soil diagnostics for determining soil functional capacity and ability to provide material and support ecosystem services.

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Salinity Status of Osere River for Irrigation: Long Term Use Implication in Selected Farmers' Field in Ilorin, Nigeria.

Henry Ahamefule*, Ridwan Taiwo*, Mathew Amana**,
Kevin Eifediyi*, Betsy Ezuogu***, Emmanuel Ihem****,
Chukwuma Nwokocha*****, Abdulateef Yusuf*,
Fatai Fatola* and Samuel Adepoju*

*Department of Agronomy, University of Ilorin, P.M.B.1515, Ilorin, Kwara state, Nigeria

** Department of Soil Science, Nasarawa state University, Lafia, Nigeria

*** Department of Crop Protection, University of Ilorin, P.M.B.1515, Ilorin, Kwara state, Nigeria

****Department of Soil Science and Technology, Federal University of Technology Owerri, Imo State, Nigeria

*****National Root Crops Research Institute, Umudike, Abia State, Nigeria

Corresponding Author: Henry Ahamefule, e-mail: ahamefule.he@unilorin.edu.ng



Abstract

Osere River is one of the important rivers that serves as a cheaper and easier disposal alternative to industries and at the same time a less expensive and dependable water supply to farmers for dry season vegetable production in Ilorin, the capital city of Kwara State, Nigeria. The edaphic aftermath of the use of its water for irrigation was investigated using a Randomized Complete Block Design (RCBD) in a two way factorial experiment. Factors comprised of fifty meter distance intervals (50 and 100 m) downstream and a control (50 m upstream) of a soap industry effluent discharge point and irrigation duration (0, 10, 20 and 30 years). River water samples indicated that the activities of the soap industry did not lead to its increased electrical conductivity (which signifies presence of dissolved salts and/or impurities), however soils under prolonged irrigation (up to 10 years) showed signs of salt induced structural deterioration (MWD). Farm soils 50 m downstream showed the lowest structural stability (MWD = 0.77 mm) and highest % silt of 21.2 whereas those located 100 m downstream indicated highest MWD of 1.10 mm. The consequent soil structural degradation was tied to elevated values of sodium adsorption ratio (SAR) following prolonged irrigation.

Keywords: Osere River, salinity, soil structural stability and soil chemical properties

Introduction

Water is essential for the sustenance of human, plant and animal life and constitutes about 70% of the Earth's surface. Water pollution is a major problem in the global context. Polluted water has been found to be a leading cause of diseases and deaths worldwide, accounting for the deaths of more than 14,000 people daily (Pink, 2006). In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. In a recent national report on water quality in the United States, 45 percent of assessed stream miles, 47 percent of assessed lake acres, and 32 percent of assessed bay and estuarine square miles were classified as polluted (Pink, 2006). Water body contaminations have also been reported in Nigeria, for instance in Ogun River, where industrial effluents from Lagos and Abeokuta is discharged (Jaji, et al., 2007). The

river was reported to have high level of turbidity, fecal coliform, iron, oil and grease (Jaji, et al, 2007). The valleys which convey this water are also prone to pollution from human activities such as road/bridge constructions which are major yardsticks for good governance in Nigeria. Polluted water consists of Industrial effluents, sewage water, and rain water. The use of this type of water is a common practice in agriculture. Estimation indicates that more than fifty countries of the world with an area of twenty million hectares are supplied with polluted or partially treated polluted water (Mahmood, 2006). In poor countries of the world more than 80% polluted water has been used for irrigation (Mara and Cairncross, 1989). Farmers use polluted water to save their expenses (Ibrahim and Salmon, 1992). With the recent trends of unpredictable rainfall patterns and climate change, these polluted water bodies and valleys are often used in augmenting inland agricultural production (the cultivation of valley bottom called Fadama in Nigeria). Polluted irrigation water may completely render agricultural soils unproductive through salt build-up. It is as a result of such accumulation that extensive areas in the arid and semi-arid region of Nigeria have gone out of cultivation (Zata, et al., 2008). It is well recognized that the salinity of an irrigation water and the sodium adsorption ratio (SAR) have an interactive effect on soil physical properties (Frenkel, 1984). Elevated values of SAR result in decreased hydraulic conductivity decreased aggregate stability, clay dispersion, swelling of expandable clays, surface crusting and reduced workability (Frenkel et al., 1978). On very salty sites a complete loss of groundcover and visible salt crystals often occur on the soil surface making it vulnerable to erosion (Greenway, 1980). As salts accumulate in soils they can reach levels that affect the environment through loss of productive species and dominance of salt-tolerant species (Tenison, 2009), decline of native vegetation, loss of habitat, loss of nesting sites and decline in bird populations, decline in wildlife fauna other than birds, reduced food for wildlife populations, increased soil and wind erosion, reduced, decline in fish and aquatic populations, reduced aesthetic value, reduced recreational and tourism values, reduced biodiversity in stream fauna, riparian vegetation and wetlands, increases in weeds and undesirable changes in plant populations and damage to state/national parks and wildlife sanctuaries.

OSERE River in Ilorin which serves as a source of irrigation water to many farmers was reported as polluted (with slightly alkaline pH) by Adeyemi-ale et al.(2014). The pollution of this river can be traced to the untreated effluent discharged into the river by the industries situated along the river course. Some (soap and detergent) effluents discharged by these industries are known to contain salts such as sodium and magnesium which causes water salinity (Ogundiran et al., 2014) and consequently soil salinity when used for irrigation. The long term use of this water for irrigation may bring about increased soil exchangeable sodium percentage and sodium adsorption ratio which may result in poor soil quality (soil crusting, reduced total porosity, aeration, water penetration and water redistribution). Against this backdrop, there is therefore need to assess the extent of the pollution of Osere River and also the extent of soil degradation occasioned by the use of the water for irrigation.

Materials and Methods

Description of Experimental Location

Ilorin is the capital of Kwara state, Nigeria. It lies by latitude 8° 35' E and longitude 4° 35' N (Jimoh, 1999) with a total land area of about 100 km² (Kwara State Government, 2007). For administrative purposes, it is divided into Ilorin West, Ilorin East, Ilorin South and Moro Local Government Areas (Oyebanji, 1993). The climate of Ilorin is the humid tropic type and characterized by both the wet and dry seasons with mean annual temperature that ranges from 25 - 28.9 °C. The annual mean rainfall is about 1150 mm, exhibiting the bimodal pattern between April and October of every year. Days are very hot during the dry season from November to February, temperature typically ranges from 33 - 34 °C while from

February to April, values are frequently between 34.6 and 37 °C. Essentially, Ilorin is located in the transition zone between the deciduous forest (rainforest) of the southwest and the savannah grasslands of the north (Oyegun, 1982).

The vegetation of Ilorin is composed of species of plants such as locust bean trees, shea butter trees, acacia trees, baobab trees, elephant grasses, shrubs and herbaceous plants among others (Jimoh, 1999). Jimoh (1999) reported that Ilorin city is underlain by basement complex parent material which is composed largely of metamorphic rocks especially gneiss and resistant quartzite. The soil of Ilorin is formed from the Precambrian basement complex rocks and it is under the grassland savannah forest cover and belong to the soil group called “Ferruginous soil” which are reddish-brown in color with a proportion of clay content. The dominant clay type is the kaolinite clay and illite group.

The study area covers selected portions of Osere River and its bank, located at Ilorin west local government. According to Adeyemi-ale et al., (2014) Osere River lies between latitude 8°49' N and longitude 4°54' E. The River is not the main river in Ilorin and flows in North-south direction (Oyebanji, 1993). This research was carried out along the river banks where farmers use the water for irrigation. Various types and forms of effluents drain into this river from various sources leading to its pollution. Some identified effluents include sewage, industrial wastes and agricultural chemicals as corroborated by Adeyemi-ale et al., (2014) and Ogundiran et al., (2014).

Experimental Design

The experiment was a Randomized Complete Block Design (RCBD) in a two (2) way factorial.

Factor A was distance between sources of irrigation water. The sources of irrigation water were 50 m upstream (control), 50 and 100 m downstream with approximate GPS locations of 8° 46'37''55 E, 4° 53'88''92 N; 8° 46'40''95 E, 4° 53'89''78 N and 8° 46'34''97 E, 4° 53'87''03 N respectively; whereas Factor B was the duration/history (years) of irrigation (10, 20 and 30 years) which was obtained by interviewing the farmers and nearby residents. Three (3) plots with the same irrigation history at each farm site were selected to serve as replicates. The selected farmers belonged to the same social class and shared similar practices [cultivated *Amaranthus* Spp., planted on beds, applied NPK (15:15:15), manual weeding and sprinkler irrigation]. Factor A was aimed at determining the effect of the effluent water discharged by a soap/detergent industry at a point between control and 50 m downstream of Osere River.

Layout of the experiment

Three (3) farm sites along Osere River (downstream) were selected at a distance of 0, 50 and 100 meters from a control point. Each plot measured 12 × 10 m with eight (8) beds each measuring 5 × 2 m. A plot 50m away (upstream) from an effluent discharge point was used as control. The effluent source was soap industry.

Data Collection

Water Sampling

Nine (9) river water samples which comprised of six (6) Osere River water samples collected 50 and 100 m downstream and (3) control sample (fifty meters upstream of effluent discharge point) referred to as 0 m sample, were taken to the laboratory for analysis.

Soil Sampling

Twelve (12) auger top soil samples were collected at each site (0 – 15 cm soil depth) and bulked accordingly (0, 10, 20 and 30 years irrigation duration) and a composite of four samples taken to represent each of the irrigation durations. Twelve undisturbed core soil samples were also collected from each site. All the samples were bagged in polyethylene plastic bags and taken to the laboratory analyses.

Preparation of soil for physical and chemical analyses

The soil samples were air dried and sieved with a 4.75mm mesh sieve size to remove stones, plant roots and have the soil of uniform particle size before carrying out physical analyses whereas 2mm sieve size was used to prepare samples for chemical analyses in the laboratory.

Laboratory Analyses

Physical Analyses

Soil texture

Soil textural class determination was done using hydrometer method according to Bouyoucos (1936) and calculated thus:

$$\% \text{Silt + Clay} = \frac{40 \text{ seconds corrected hydrometer reading} \times 100}{\text{Weight of sample}}$$

$$\% \text{Clay} = \frac{2 \text{ hours corrected hydrometer reading} \times 100}{\text{Weight of sample}}$$

$$\% \text{Sand} = 100 - (\% \text{silt} + \text{clay})$$

$$\% \text{Silt} = \% \text{Silt + Clay} - \% \text{Clay}$$

Soil bulk density

Soil bulk density was determined according to Blake and Hartage (1986), and calculated thus:

$$\text{Dry bulk density} = \frac{\text{Mass of oven dried soil}}{\text{Total volume of soil}}$$

Total Porosity

The total porosity (TP) was estimated from the bulk density (BD) and an assumed particle density (PD) of 2.65g/cm³ thus:

$$\text{TP} = 100 \left(1 - \frac{\text{BD}}{\text{PD}} \right)$$

Macro porosity (MaP) was calculated thus:

$$\text{MaP} = \frac{\text{Volume of water drained at 60cm tension}}{\text{Volume of bulk soil}}$$

Micro porosity (MiP) calculated thus:

$$\text{MiP} = \text{Total Porosity} - \text{Macro porosity}$$

Saturated hydraulic conductivity (Ksat)

Saturated hydraulic conductivity (Ksat) was determined by the constant head permeameter method (Klute and Dirksen, 1986).

The transposed Darcy's equation was used to calculate Ksat thus:

$$\text{Ksat} = \frac{Q}{A_t} \cdot \frac{L}{\Delta H}$$

Where:

Ksat = hydraulic conductivity (cm/hr)

Q = volume of percolate (cm³)

L = height of core (cm)

ΔH = hydraulic head difference (cm)

A = cross sectional area of core (cm²)

t = time required to collect percolate (hours)

Mean weight diameter

The distribution of aggregates was determined by the wet sieving technique described by Kemper and Rosenau (1986). In this procedure 25g of the less than 4.75mm air dried soil samples was emptied into the topmost of a nest of sieves of diameter 2, 1, 0.5, 0.25mm and pre-soaked in distilled water for 5minutes before oscillating in water 20 times (along a 4cm amplitude) at the rate of 1 oscillation per second. After wet sieving, the resistant aggregates on each sieve were transferred into beakers, oven dried at 105°C for 24 hours and then re-weighed. The percentage ratio of the aggregate in each sieve was calculated and thus represents the water stable aggregate of size classes; 4.75 – 2.00, 2.00 – 1.00, 1.00 – 0.05, 0.05 – 0.25 and less than 0.25mm. The method of Van Bavel (1950), as modified by Kemper and Rosenau (1986), was used to determine mean weight diameter of water stable aggregate thus:

$$MWD = \sum_{i=1}^n X_i W_i$$

Where MWD = mean weight diameter of water stable aggregate.

X = diameter of each size fraction in (mm) and

W = proportion of the total samples weight in the corresponding size fraction.

Chemical Analyses:

Soil pH

Soil pH was determined according to Chofield and Taylor (1995) in which a combination electrode was immersed into the soil - water suspension and the soil pH was read.

Determination of electrical conductivity in soil and water samples

Electrical conductivity was determined in 1:2.5 soil/aqueous extract at 25°C as described by Black et al., (1995).

Determination of Calcium (Ca), Magnesium (Mg) and Sodium(Na)

Soil samples were extracted with an excess of 1N ammonium acetate (NH₄OAC). The amounts of exchangeable sodium (Na), calcium (Ca) and Magnesium (Mg) in the extract were determined by Atomic Absorption Spectrophotometer (AAS).

Salinity hazard determination

Salinity hazard was calculated as:

$$SAR = Na / (0.5 \times (Ca + Mg))^{1/2}$$

Exchangeable sodium percentage (ESP) as:

$$ESP = (Exch. Na / CEC) \times 100$$

Data Analysis

Data collected was analyzed statistically using analysis of variance (ANOVA) with Genstat, and significant means separated using least significant difference (LSD).

Results and Discussion

Data on the electrical conductivity of Osere River which is an indicator of the concentration of dissolved electrolyte ions in the water is shown in Table 1. The result indicated that distance between irrigation water sources did not have significant effect on the electrical conductivity of the irrigation water. Implying that the electrical conductivity of the water the farmers use for the irrigation of the three farm sites sampled were the same. It could also be further interpreted to mean that the human activities (including the activities of the soap and detergent industry) between the sampling points were not introducing significant

level of impurities into the river. It has been reported that the normal range of electrical conductivity of most streams and rivers (depending on geology) range between 50 – 150 microsiemens per centimeter (Sharon, 1997). The highest average value recorded in this work (0.022dSm^{-1}) translates to 22 microsiemens per centimeter, which was observed 50 m downstream.

Table 2 shows that distance between irrigation water sources along Osere River significantly affected the pH of the irrigated soils. Soils collected 50 m (downstream) away from control (50 m upstream) showed significantly higher pH than soils at control and at 100 m distance away from control. The observation may be attributable to the long term effect of effluent water discharge into the river by a soap industry just before 50 m sampling point. It is thought that the effluent water is alkaline, as buttressed by the report of Adeyemi-ale, (2014). This condition of the effluent water may have accounted for the increased salinity (slightly alkaline) of: 1.soils in farms irrigated with water sourced close to (downstream) the effluent discharges point and 2.soils under irrigation durations up to 20 years. Furthermore, the effect of irrigation duration on the pH of the irrigated soils also significantly increased as the duration increased from 10–20 years, though generally no particular trend was observed. The interaction showed that soils irrigated with water from 50 m distance (downstream) away from control had the highest pH after 20 years. The result suggests a gradual build-up of saline salts from a poorly concentrated or irregularly distributed background of natural or industrial origin around the 50 m location. Soil pH is known to influence nutrient availability. According to Pratt and Suarez (1990) elevated pH also has an adverse impact on soil stability.

Table 1: Effect of distance between irrigation water sources on the Electrical conductivity (dSm^{-1}) of Osere River water

	Distance of water source in meters (Factor A)		
	Control	50	100
	0.017	0.017	0.017
	0.017	0.022	0.019
	0.017	0.025	0.025
	0.017	0.022	0.020
MEAN	0.017	0.022	0.020

LSD 0.05 for Factor A = Ns, Ns = non-significant

Table 2. Effect of distance between water sources and irrigation duration on pH of selected irrigated farmlands along Osere River bank

Irrigation duration in years (Factor B)	Distance between water sources in meters (Factor A)			Mean
	Control	50	100	
0	7.3	7.3	7.3	7.3
10	7.3	7.3	7.3	7.2
20	7.3	7.5	7.4	7.4
30	7.3	7.4	7.3	7.4
Mean	7.3	7.4	7.3	

LSD 0.05 for Factor A = 0.1, Factor B = 0.1, $A \times B = *$

Table 3 shows that distance between irrigation water sources had no significant effect on the bulk density of the irrigated soils. The results also showed that the use of Osere River for irrigation for a period up to 30 years did not significantly ($P < 0.05$) affect the bulk density of the irrigated soils. The interaction between irrigation water source and irrigation duration was not significant.

Table 4 shows that distance between irrigation water sources had no significant effect on the total porosity of irrigated soils. The effect of irrigation duration also did not have significant effect on the total porosity of the irrigated soils. There was no significant interaction between irrigation water sources and irrigation duration.

The results also indicated that distance between irrigation water sources did not lead to significant a difference in the exchangeable sodium percentage (ESP) of soils (Table 5). The effect of irrigation duration also did not have significant effect on the ESP of the irrigated soils. There was no significant interaction between irrigation water sources and irrigation duration.

The distance between irrigation water sources and irrigation duration was however found to have significant effect on the sodium absorption ratio (SAR) of the irrigated soils (Table 6). Soils located 50 m away from control showed significantly higher SAR than soils at control (50 m upstream) and 100 m distance (downstream) away from control. This observation could be attributable to the effect of effluent water discharged into the river by the soap industry located just before 50 m sampling point.

Table 3. Effect of distance between water sources and irrigation duration on bulk density (g/cm^3) of selected irrigated farmlands along Osere river bank

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	0.663	0.663	0.663	0.663
10	0.663	0.743	0.540	0.648
20	0.663	0.757	0.557	0.648
30	0.663	0.690	0.557	0.636
MEAN	0.663	0.702	0.579	

LSD 0.05 for Factor A = Ns, Factor B = Ns, $A \times B$ = Ns, Ns = non-significant

Table 4. Effect of distance between water sources and irrigation duration on total porosity (%) of selected irrigated farms along Osere river bank

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	74.8	74.8	74.8	74.8
10	74.8	72.2	79.6	75.5
20	74.8	71.4	79.0	75.1
30	74.8	74.0	78.2	75.6
MEAN	74.8	73.1	77.9	

LSD 0.05 for Factor A = Ns, Factor B = Ns, $A \times B$ = Ns, Ns = Non-significant

It is thought that the effluent water contains Sodium (Na) ions, which in higher concentration around the discharge point leads to increased SAR of irrigated soils; however the effect appeared to be reduced downstream probably due to dilution of the effluent water into the larger water body. Sodium absorption ratio significantly increased when the duration of irrigation increased from 10 – 20 years. The interaction showed that soils irrigated for 20 years with water from 50 m downstream of control point had the highest SAR value whereas soils 100 m downstream with irrigation history of 20 years had lowest SAR value. Elevated values of SAR is known to lead to soil disaggregation and hence impeded water percolation into the soil (Frenkel, et al.,1978) and consequent signs of water stress on plants.

Table 5. *Effect of distance between water sources and irrigation duration on the exchangeable sodium percentage (%) of irrigated farmlands.*

Irrigation history in years (FactorB)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	53.4	53.4	53.4	53.4
10	53.4	46.3	49.4	49.7
20	53.4	46.1	50.5	50.3
30	53.4	54.2	33.2	46.9
MEAN	53.4	50.0	46.6	

LSD 0.05 for Factor A = Ns, Factor B = Ns, A × B = Ns, Ns = non-significant

Table 6. *Effect of distance between water sources and irrigation duration on sodium adsorption ratio (meq/l) of irrigated soil*

Irrigation History in years (Factor B)	Distance of water source in meters (FactorA)			
	Control	50	100	MEAN
0	0.13	0.13	0.13	0.13
10	0.13	0.18	0.16	0.15
20	0.13	0.24	0.12	0.16
30	0.13	0.17	0.13	0.14
MEAN	0.13	0.18	0.14	

*LSD 0.05 for Factor A = 0.047, Factor B = 0.057, A × B = *, * = significant at 1 % level of probability*

Table 7 shows that distance between irrigation water sources and irrigation duration had significant effect on the mean weight diameter (MWD) of the irrigated soils. Higher values of MWD would indicate comparatively better soil structure and higher soil stability. Soils collected in farms located 50 m downstream showed the lowest (0.77 mm) MWD whereas soils collected at 100 m downstream of control point showed the highest (1.10 mm) MWD. This observation may be attributable to the effect of Na probably contained in the effluent discharged into the river before 50 m sampling point by a nearby soap industry. Sodium (Na) is implicated in the disaggregation (poor structure) of soil as observed in location 50 m. The MWD of the irrigated soil decreased as the duration of irrigation increased, with soils under 30 years of irrigation having the lowest (0.66 mm) MWD compared to the highest (1.12 mm) in control soils. The interaction between both factors showed that control soils irrigated with water sourced from 100 m downstream had the highest (1.37 mm) MWD whereas soils from 50 m downstream under irrigation history of 30 years was observed to have the lowest (0.14 mm) MWD. Van de Graaff and Patterson (2001)

reported that high sodicity causes excessive swelling of clay minerals which weakens soil aggregates, causing structural collapse and closing-off of soil pores. Consequently, water and air movement through sodic soils are severely restricted and affected soils are prone to erosion. The results clearly shows that though the salinity of Osere River (indicated by its water electrical conductivity values obtained at the various sampling points) is not significantly increased by the activities of the soap industry, however the prolonged use of the river water, especially close to the companies effluent discharge point for irrigation purposes could predispose the soil to adverse symptoms of soil salinity.

The silt separate of soils irrigated with water sourced from 50 m downstream of Osere River relative to control point indicated significantly ($P < 0.05$) higher content compared to 0 m (control) and 100 m downstream. Irrigated soils 100 m downstream also showed higher silt content compared with control. Values ranged between 20.0 – 21.2 %.

Table 7: Effect of source of water and irrigation duration on mean weight diameter of selected irrigated farmlands along Osere river bank

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	0.97	1.02	1.37	1.12
10	0.97	0.96	1.19	1.04
20	0.97	0.97	0.97	0.97
30	0.97	0.14	0.87	0.66
MEAN	0.97	0.77	1.1	

*LSD 0.05 Factor A = 0.32 Factor B = 0.39 $A \times B = *$*

This observation may likely corroborate a salty (Na) effluent discharge between control point and 50 m downstream. The dispersing action of Na may have mobilized silt fraction from the river bed and bank, resulting in a colloidal water suspension used by farmers for irrigation along the river bank. Lal (1997) reported high mobility of soil silt fraction. The results however showed significantly lower accumulation of silt in farms as the irrigation duration increased from 10–30 years with values ranging between 21.7–20.4% respectively. It is thought that silt mobility due to rainfall may have retarded the build-up of silt over the years. The interaction showed that soils irrigated for 10years at 50 m downstream had the highest % silt content.

Table 8: Effect of distance between water sources and irrigation duration on silt content (%) of irrigated soils.

Irrigation History in years (Factor B)	Distance of water source in meters (Factor A)			
	Control	50	100	MEAN
0	20.0	20.0	20.0	20.0
10	20.0	22.7	20.3	21.7
20	20.0	21.3	21.0	20.7
30	20.0	20.8	20.3	20.4
MEAN	20.0	21.2	20.9	

*LSD 0.05 Factor A = 0.8 Factor B = 1.3 $A \times B = * * =$ significant at 1 % level of probability*

Conclusion

It could be concluded from the study that Osere river water at the points sampled was not saline, however prolonged use of the water for irrigation of farmlands on the bank led to gradual build-up of Na salt resulting in increased soil salinity (SAR) which negatively impacted on the stability of soil aggregates. The study also suggests the release of Na salt from a nearby soap/detergent industry or anthropogenic sources close to this industry.

For sustainable farming operations under irrigation from Osere River, farmers would require regular application of Calcium rich organic amendments or agricultural limes which may be applied biannually.

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Detection of Similar Homoclimates by Numerical Analysis

Alexander N. Sadovski



Bulgarian Science Center of the IEAS

Corresponding Author: Alexander N. Sadovski, e-mail: bsc.ieas@yahoo.com

Abstract

Numerical methods including cluster analysis, similarity measures and other techniques were used to compare climatic data from Bulgarian stations in order to classify them according similar homoclimate. Using Euclidean distance and City-block (Manhattan) distance, data from Bulgaria and states of the USA were analyzed to reveal homoclimate. Similarities in conditions for growth and development of crops of these areas were also determined.

Key words: homoclimate, homoclimate, cluster analysis, similarity measures.

Introduction

In many fields including agroclimatology, pedology, plant introduction, environmental health and agricultural transfer, detection of areas of similar climate is of significant interest. It helps in solving completely different problems like allocation of appropriate agricultural crops to given areas and evaluation of bioclimatic resources in connection with genetic status of population on certain locations.

Definition of **homoclimate** (Merriam-Webster): a climatically similar environment; specifically: a region climatically similar to another specified region

Several authors have carried out comparisons of climate in different parts of the world. The term "homoclimate" is used by Prescott (1938) for areas with similar climate. Others have used the term "homoclimate" (Meigs, 1953). Russell and Moore (1970) give the exact definition of both terms. The term homoclimate refers to two or more stations that possess a similar climate, whereas the term homoclimate refers to areas or regions, which possess similar climate. So comparisons are made between meteorological stations and they define homoclimates (Russell, 1982). In the case of considering local conditions on small confined locations we are using term "local homoclimates".

In Bulgaria intensive studies on the climate and climatic regioning have been carried out with reference to global areas as the Balkan Peninsula (Nojarov, 2017) and Bulgaria (Stanev et al., 1991). Most of these studies (CIA, 1943), (Dimitrov, 1968) and (Stanev et al., 1991) provide a common characteristic of the climate in the country. However, no attempt is made to find similarities of different locations in a numerical form. Only Nojarov has made attempt to use method of cluster analysis with Sea Level Pressure data for the period 1950–2012 at 61 stations located in or around the Balkan Peninsula. A

hierarchical clustering technique – average linkage between groups with Pearson correlation for measurement of intervals was employed in the research.

The development of numerical methods for data analysis and computer technique enables to a considerable degree the studies and search for homoclimates. New multivariate statistical methods allow simultaneous consideration of many meteorological parameters for assessment of climate at any one location.

Homoclimate of Bulgarian stations

Climatic data from 114 stations in Bulgaria (Lingova, Kiuchukova, 1979-1982) and Annual Meteorological Books (NIMH, 2011-2017) are used for the present study. Six parameters are considered for all stations on monthly bases (January - December): mean air temperature, absolute maximal and minimal air temperatures, relative humidity, sum of precipitation and wind speed.

For our study we apply joining (tree clustering) Ward's method. This method is distinct from all other methods because it uses an analysis of variance approach to evaluate the distances between clusters. This method attempts to minimize the Sum of Squares of any two (hypothetical) clusters that can be formed at each step. Refer to Ward (1963) for details concerning this method. In general, this method is regarded as very efficient; however, it tends to create clusters of small size.

Euclidean distance measure is used:

$$\text{distance}(x,y) = \{\sum_i (x_i - y_i)^2\}^{1/2}$$

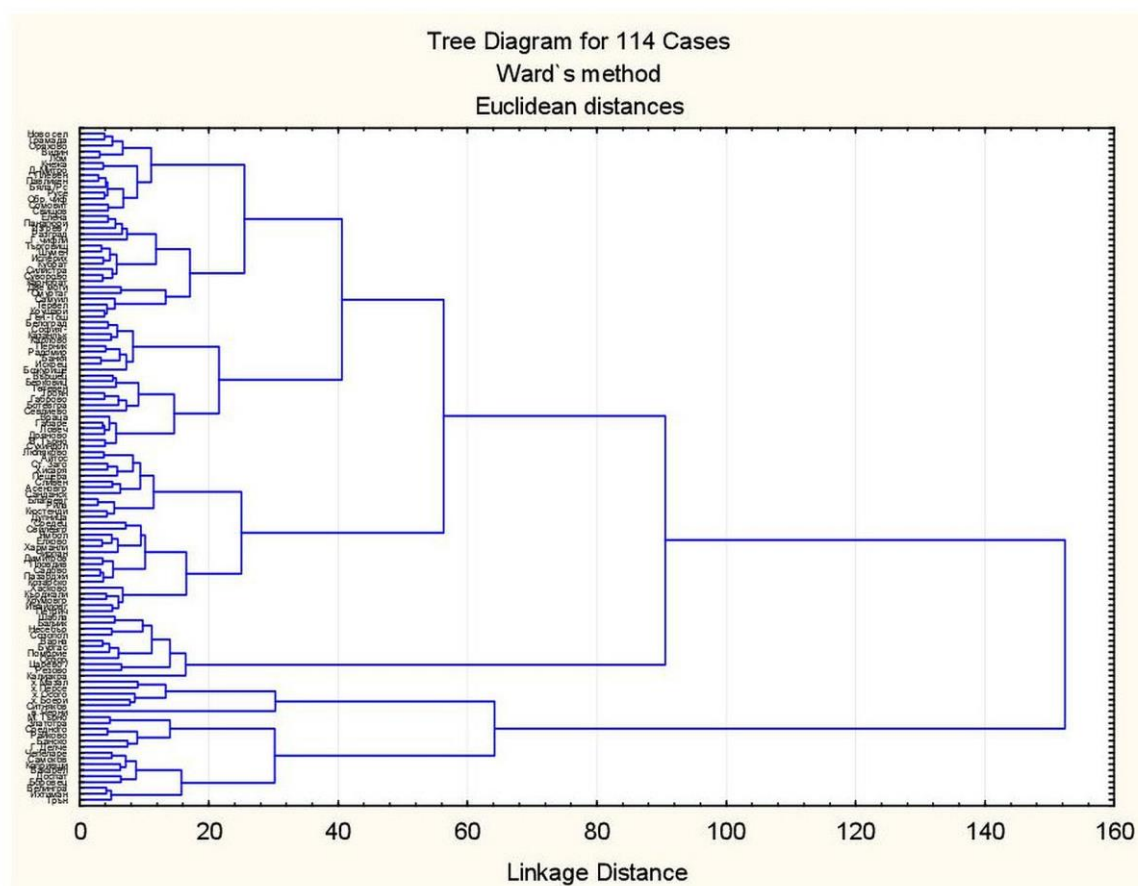


Figure 1. Graphical presentation of results from cluster analysis.

The final result consists of five clusters, which combine stations with similar homoclimate.

Cluster 1 contains 13 cases - locations along the Black Sea coast:

Omurtag, Shabla, Kaliakra, Balchik, Gen.-Toshevo, Varna, Burgas, Nessebar, Pomorie, Sozopol, Tsarevo, Rezovo, Obzor.

Cluster 2 contains 49 cases - locations from Danubian plain and middle South Bulgaria:

Novo Selo, Vidin, Gramada, Belogradchik, Lom, Vratsa, Gabare, Knezha, Oryahovo, Pleven, Somovit, D. Mitropolia, Lovech, Sevlievo, Dryanovo, Pavlikeni, Elena, Svishtov, Rousse, Dve Mogili, Obr. Chiflik, Byala/Rs, Targovishte, Razgrad, Samuil, Isperih, Kubrat, Silistra, Shumen, Tervel, Krushari, G. Chiflik, Suvorovo, Karnobat, Sredets, Yambol, Elhovo, Chirpan, Kazanlak, Svilengrad, Harmanli, Dimitrovgrad, Plovdiv, Sadovo, Pazardjik, Radomir, Sofia, Bozhurishte, Botevgrad.

Cluster 3 contains 24 cases - locations from mountainous regions:

Varshets, Berkovitsa, Teteven, Troyan, Gabrovo, Izgrev, M. Tarnovo, Srednogorie, Chepelare, Raikovo, Zlatograd, Dospat, Velingrad, Panagyurishte, Bansko, Pernik, Tran, Bankya, Ihtiman, Koprivshtitsa, Borovets, Samokov, Iskrets, Vakarel.

Cluster 4 contains 6 cases - locations in high mountain areas:

x. Mazalat, x. Persenk, x. Osogovo, Cherni vrah, x. Boerica, Sitnyakovo.

Cluster 5 contains 22 cases - locations in pre-Balkan, sub-Balkan and south-western Bulgaria:

Veliko Tarnovo, Suhindol, Lyulyakovo, Aytos, Sliven, St. Zagora, Haskovo, Kardzhali, Krumovgrad, Ivaylovgrad, Asenovgrad, Karlovo, Hissarya, Kozarsko, Peshtera, Blagoevgrad, Sandanski, Petrich, G. Delchev, Kyustendil, Dupnitsa, Rila.

The results can clearly be displayed on one map of the country.

Homoclimate of Bulgaria and USA

We think that in solving different problems like allocation of appropriate agricultural crops, transfer of technology in agricultural practice to given areas and evaluation of bioclimatic resources, it is good to know areas or regions, which possess similar climate. This puts the task of making a comparison of the climate in Bulgaria and that of the states in the United States.

Important factors in the growth and development of crops during the vegetation period are the average daily temperatures and the amount of precipitation during the periods March - June (Tav 3-6, Pav 3-6) and August - November (Tav 8-11, Pav 8-11). For this purpose data from 41 states (U.S. Climate data), compared with the data for Bulgaria from Annual Meteorological Books (NIMH, 2011-2017), were used.

Table 1. Data from the periods March - June and August - November

State	Tav 3-6	Tav 8-11	Pav 3-6	Pav 8-11
Alabama	20.125	21.113	111.500	102.250
Arizona	25.388	27.038	9.000	20.750
Arkansas	19.125	20.263	50.000	88.250
California	13.988	15.888	35.500	8.750
Colorado	11.625	13.625	42.500	37.000
Delaware	15.225	17.450	104.500	101.750
Florida	21.263	22.463	128.250	142.500
Georgia	18.875	19.750	100.000	108.500
Idaho	13.050	14.500	29.500	11.750
Illinois	12.875	15.000	92.250	92.250
Indiana	13.313	14.613	101.750	83.750
Iowa	13.488	14.475	100.000	90.250
Kansas	15.450	16.413	103.750	93.750
Kentucky	13.900	15.638	106.250	86.250
Louisiana	22.500	23.463	136.750	131.750
Maryland	16.250	18.538	87.500	95.750
Michigan	11.075	12.988	75.500	76.750
Minnesota	11.600	12.713	78.250	97.500
Mississippi	20.038	20.800	117.500	101.750
Missouri	15.250	16.600	106.000	100.750
Montana	9.625	10.613	34.750	26.250
Nebraska	13.375	14.375	85.500	79.250
New Jersey	14.188	16.588	104.250	100.500
New Mexico	11.888	12.825	25.250	47.250
New York	14.063	16.900	101.250	101.750
North Carolina	17.413	18.238	88.750	92.000
North Dakota	9.163	10.300	49.000	50.750
Ohio	13.838	15.338	106.750	72.750
Oklahoma	18.475	19.650	99.750	88.500
Oregon	12.100	14.013	66.750	33.250
Pennsylvania	14.813	17.050	91.750	94.000
South Carolina	19.675	20.350	88.500	110.000
South Dakota	9.563	10.325	60.750	67.250
Tennessee	19.475	20.325	124.000	92.250
Texas	22.475	23.613	86.000	70.750
Utah	14.300	16.138	49.250	28.500
Virginia	16.750	18.088	94.750	102.750
Washington	11.938	13.563	62.500	40.750
West Virginia	15.200	16.263	103.000	92.750
Wisconsin	10.350	13.338	83.000	85.000
Wyoming	9.088	11.075	47.250	41.000
Bulgaria	12.986	18.562	57.979	53.609

Using these climatic variables, we can calculate the climatic similarity (homoclimate) between two areas. Several similarity measures can be applied (Clifford and Williams, 1976). We used Euclidean distance and City-block (Manhattan) distance. Another suitable alternative is Gower's similarity measure (Gower, 1971).

$$\text{City-block distance} = \frac{1}{m} \sum_{j=1}^m \left(\frac{|x_{1j} - x_{2j}|}{x_{1j} + x_{2j}} \right);$$

$$\text{Gower similarity measure} = 1 - \frac{|x_{ik} - x_{jk}|}{r_k},$$

where r_k is the range of values for the k -th variable.

The following table presents the results of the analysis representing the states closest to Bulgaria.

Table 2. Comparison of Bulgaria with the most similar USA states.

State	Euclidean distances	State	City-block (Manhattan) distances
Bulgaria	0	Bulgaria	0
North Dakota	13	Washington	23
Washington	15	North Dakota	24
South Dakota	17	South Dakota	28
Wyoming	19	Oregon	35
Colorado	23	Wyoming	35
Oregon	23	Colorado	38
Utah	27	Utah	38

The following figure illustrates the similarity of Bulgarian conditions for growth and development of crops with corresponding US states.



Figure 2. Map of USA showing states with homoclime similar to Bulgaria.

Here is interesting to show the representation of similarity between countries from Europe and Asia to North America (McCarthy, 2016). It can be seen that the countries of Eastern Europe, to which Bulgaria belongs, have a similar climate with the Northwestern states of America, which confirms our analysis and conclusions.

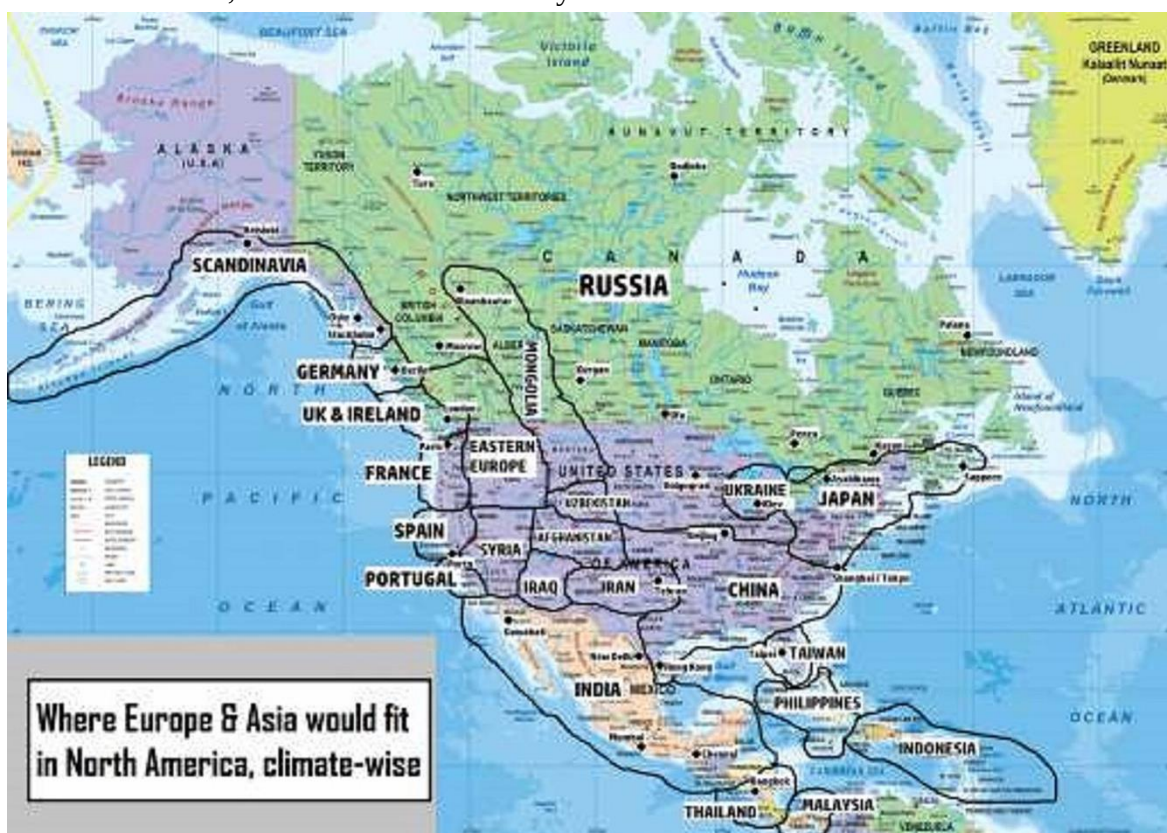


Figure 3. A climate map comparison of USA, (McCarthy, 2016).

The climate maps show some countries have what could be called a "climate twin".

Conclusion

The development of a clustering procedure and its application to meteorological data from the station in Bulgaria, provides some insight into the number and position of observation stations that are necessary to monitor adequately the climate of Bulgaria. In the article five clusters are detected and homoclimates in the country are defined.

Precise evaluation of climatically analogous regions in different countries of the world for improvement of cropping practices and introduction of improved crop varieties from one region to another requires realistic computations and detection of homoclimate for the crop-growing seasons.

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